1994 CEDAR Workshop
Boulder, Colorado
June 20-25, 1994

CEDAR Prize Lecture

by Raymond Roble
HAO/NCAR

Modelling the Circulation, Temperature and Compositional Structure of the Upper Atmosphere (30-500 km)

TGCM TEAM

HAO

E. Cicely Ridley	-	Mathematical analysis and development
Ben Foster	-	Processors, display and diagnostics
Art Richmond	-	Electrodynamics, AMIE
Barabara Emery	-	Auroral Parameterizations, AMIE
Bill Roberts	-	AMIE displays
Gang Lu	-	AMIE/TGCM runs and analysis
Maura Hagan	-	TGCM/DATA analysis and tidal boundaries
BOB DICKINSON		U. OF ARIZONA

COLLABORATORS

CASANDRA FESEN

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VICTOR FOMICHEV

TIM KILLEEN, ALAN BURNS, PAUL HAYS

FRED REES

GONZALO HERNANDEZ

GEOFF CROWLEY

FRANK MARCOS

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*

ETC., ETC., ETC.

TOM HOLZER/HAO/NSF/NASA/SPACE PHYSICS THEORY/ AIR FORCE

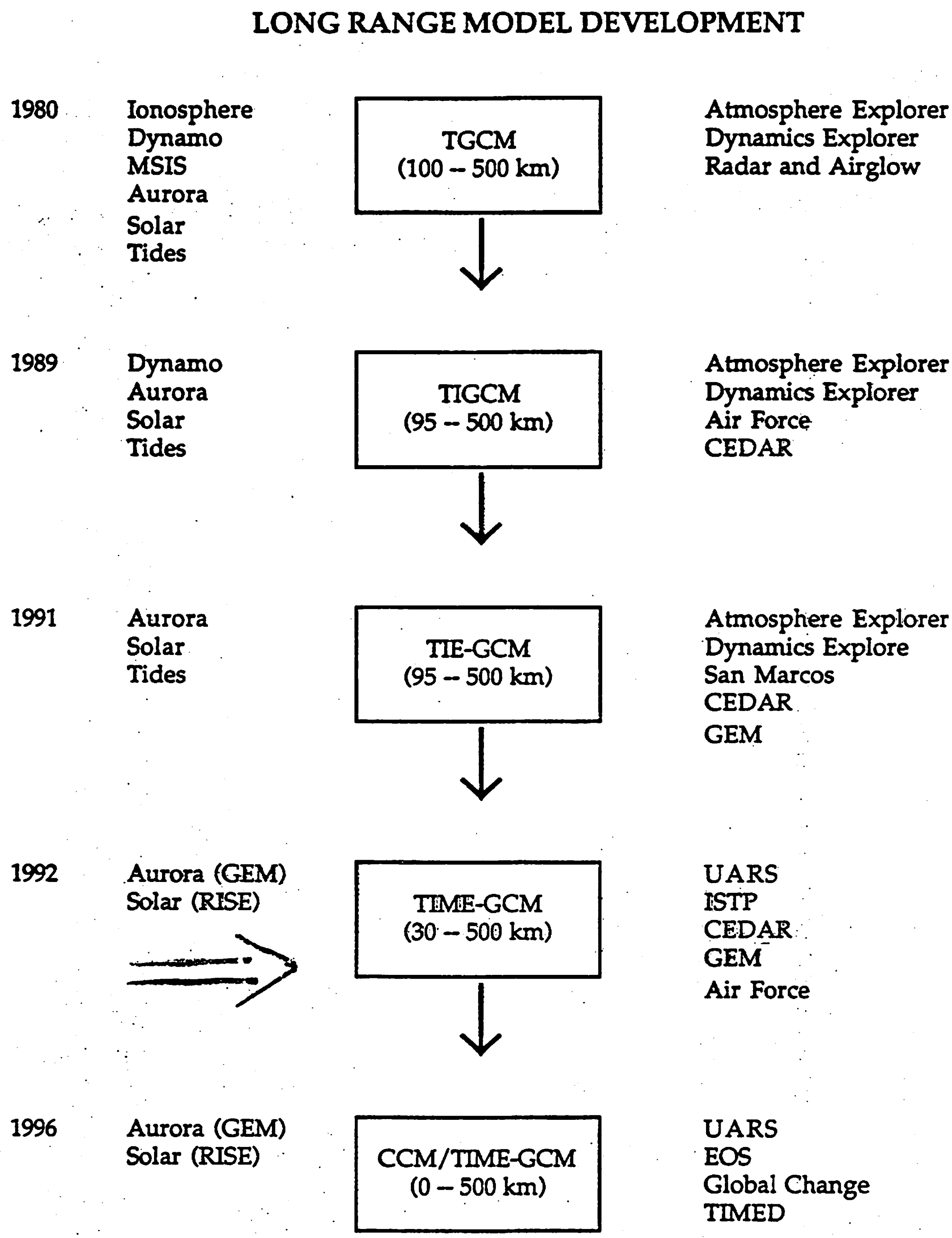


Fig. 1 Schematic illustrating past and future TGCM development. The year of model development and diminishing dependence on empirical specification is given on the left of the boxes and the programs and data sources used for GCM validation and scientific studies is given on the right. CCM refers to the NCAR community climate model.

TIE-GCM OUTPUT

- Neutral gas temperature, T_n
- Neutral winds, U, V, W
- Height of constant pressure surface, h
- Neutral composition and density

  Major – O, O_2, and N_2

  Minor – $N(^2D)$, $N(^4S)$, NO, He, and Ar

- Ion composition

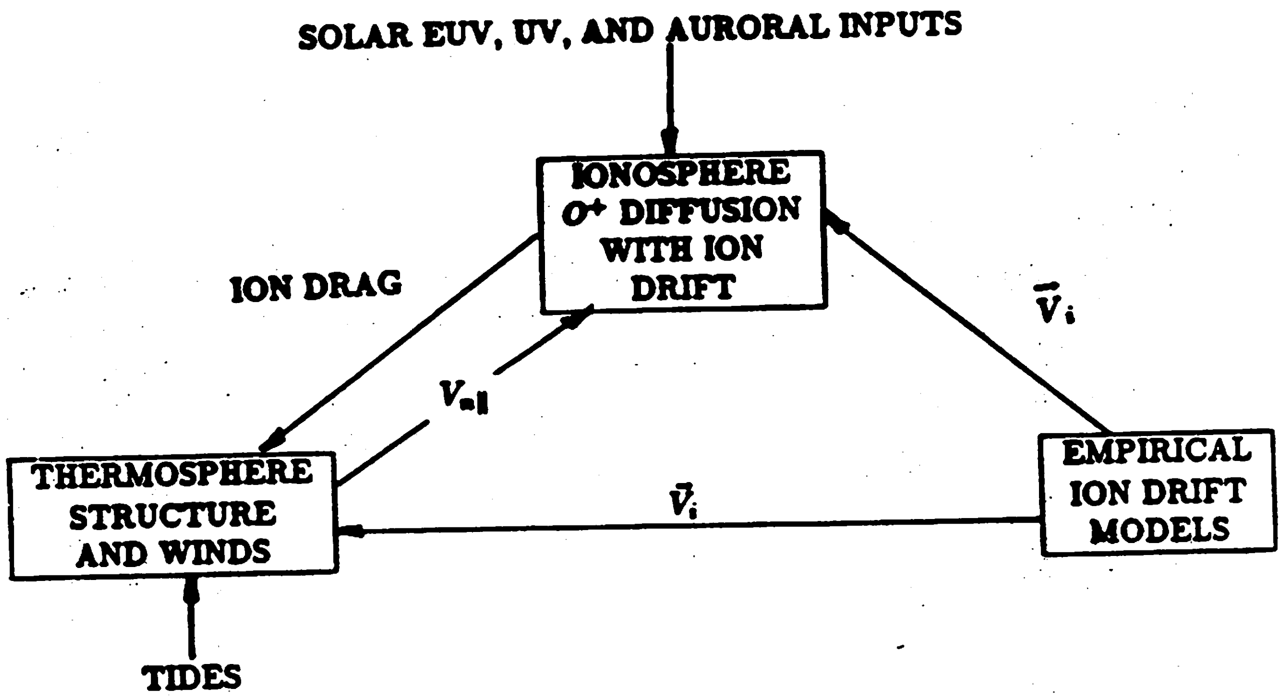
  $O^+(^2P)$, $O^+(^2D)$, $O^+(^4S)$, NO^+, O_2^+, N_2^+, and N^+ $\Sigma n_i = n_e$

  Ion temperature, T_i

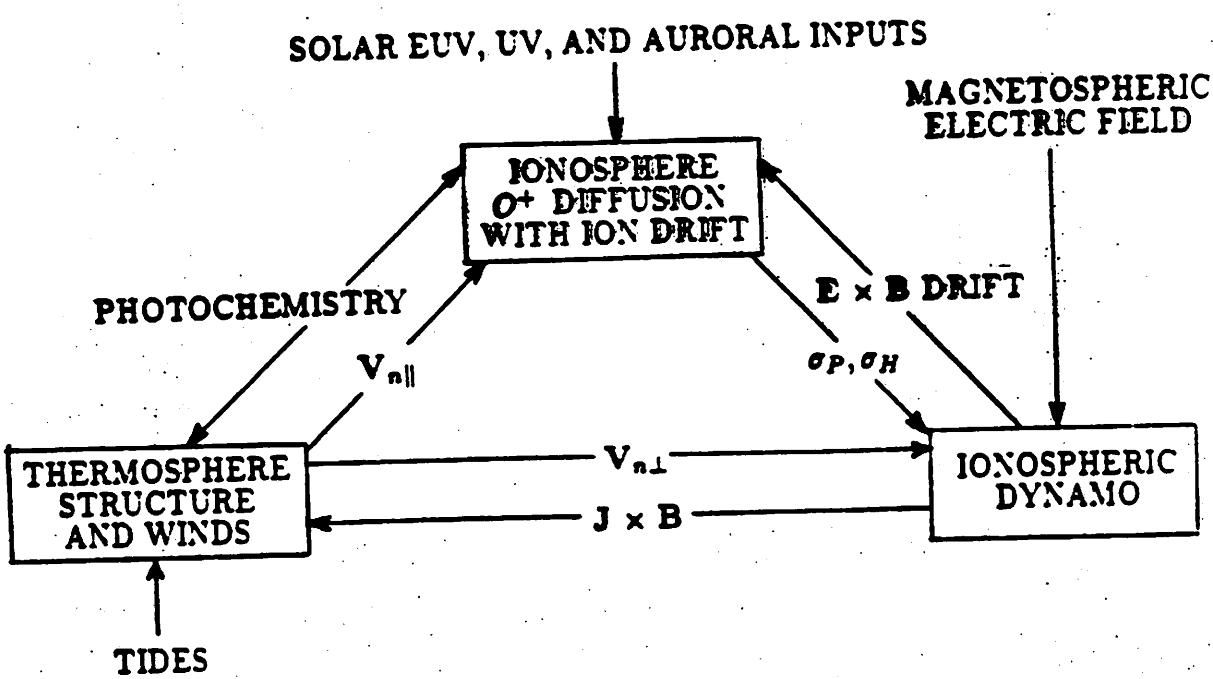
  Electron temperature, T_e

- Global distribution of electric fields $\vec{E}$ and currents $\vec{J}$

TIGCM



TIE-GCM



STANDARD MODEL.

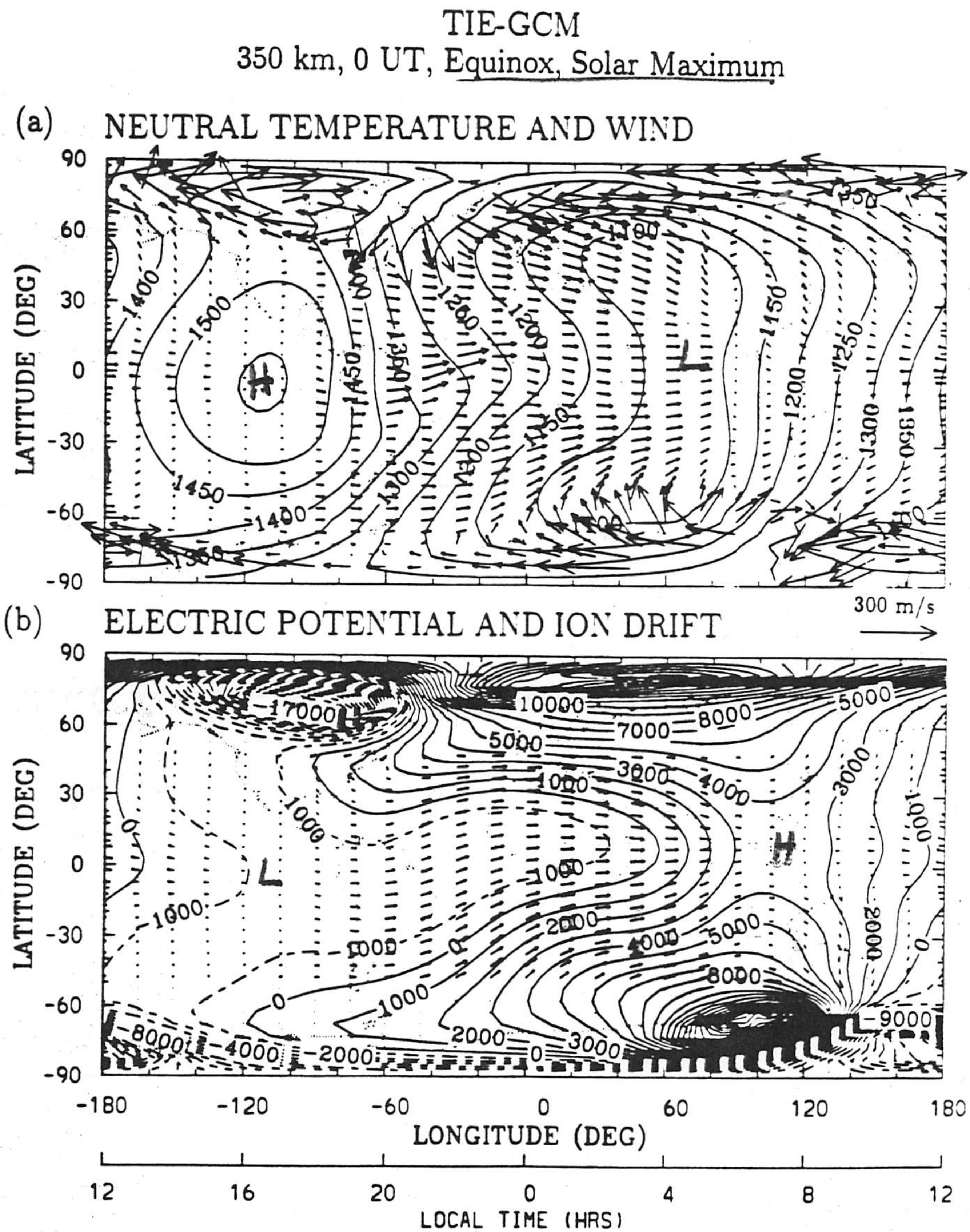

TIE-GCM
350 km, 0 UT, Equinox, Solar Maximum
(a) NEUTRAL TEMPERATURE AND WIND
(b) ELECTRIC POTENTIAL AND ION DRIFT
300 m/s
LATITUDE (DEG)
LONGITUDE (DEG)
LOCAL TIME (HRS)

Figure 2

NCAR THERMOSPHERE-IONOSPHERE-ELECTRODYNAMICS GENERAL CIRCULATION MODEL (TIE-GCM)

- Primitive equations of dynamic meteorology adapted to thermospheric heights

- Eulerian model of the ionosphere

- Horizontal grid 5° latitude × 5° longitude, geographic

- Vertical grid – 25 constant pressure surfaces, 2 grid points per scale height, 95 to 500 km

- Time step 240 or 300 S

- Global dynamo with realistic magnetic field

INPUT

- Solar EUV and UV radiation 5 to 250 nm

- Empirical ionospheric convection and auroral particle precipitation models

- Structure of upward propagating tides and other features from middle atmosphere

THERMOSPHERE-IONOSPHERE-MESOSPHERE-ELECTRODYNAMICS GENERAL CIRCULATION MODEL (TIME-GCM)

- TIE-GCM is extended downward to 30 km (10 mb) altitude
- Major species transport for O_2, N_2, and $O_X(O + O_3)$
- Minor species transport for H_2O, H_2, CH_4, CO, CO_2, $NO_X(NO + NO_2)$, $N(^4S)$, $HO_X(H + HO_2 + OH)$
- Minor species in photochemical equilibrium for $O(^1D)$, $N(^2D)$, H_2O_2, $O_2(^1\Delta_g)$, and $O_2(^1\Sigma_g)$
- LTE+ NLTE- CO_2 radiational cooling (Fomichev parameterization); O_3 (9.6 um)
- Fritts gravity wave parameterization
- Boundary conditions
  - (a) Lower: specified mixing ratios for O_2, N_2, H_2O, H_2, CH_4, CO_2, CO, O_X, and NO_X G-S model – 10 mb
  - (b) Upper: diffusive equilibrium for all species except H where exospheric escape is specified
  - (c) Dynamics based on tidal theory at various frequencies (10 mb)
    - NMC 10MB GEOPOTENTIAL HEIGHT DATA
- D-region ion chemistry
- Energetic electron and proton particle degradation

MAJOR TIME-GCM OBJECTIVES

- How deep into the atmosphere do effects of solar variability penetrate?

- How do disturbances from lower atmosphere affect middle (30 - 100 KM) and upper atmosphere (100 - 500 KM)?

  + Couplings

    * Solar Radiative
    * Auroral
    * Chemical
    * Radiative
    * Electrical
    * Dynamic

- How will the upper atmosphere and ionosphere respond to global change?

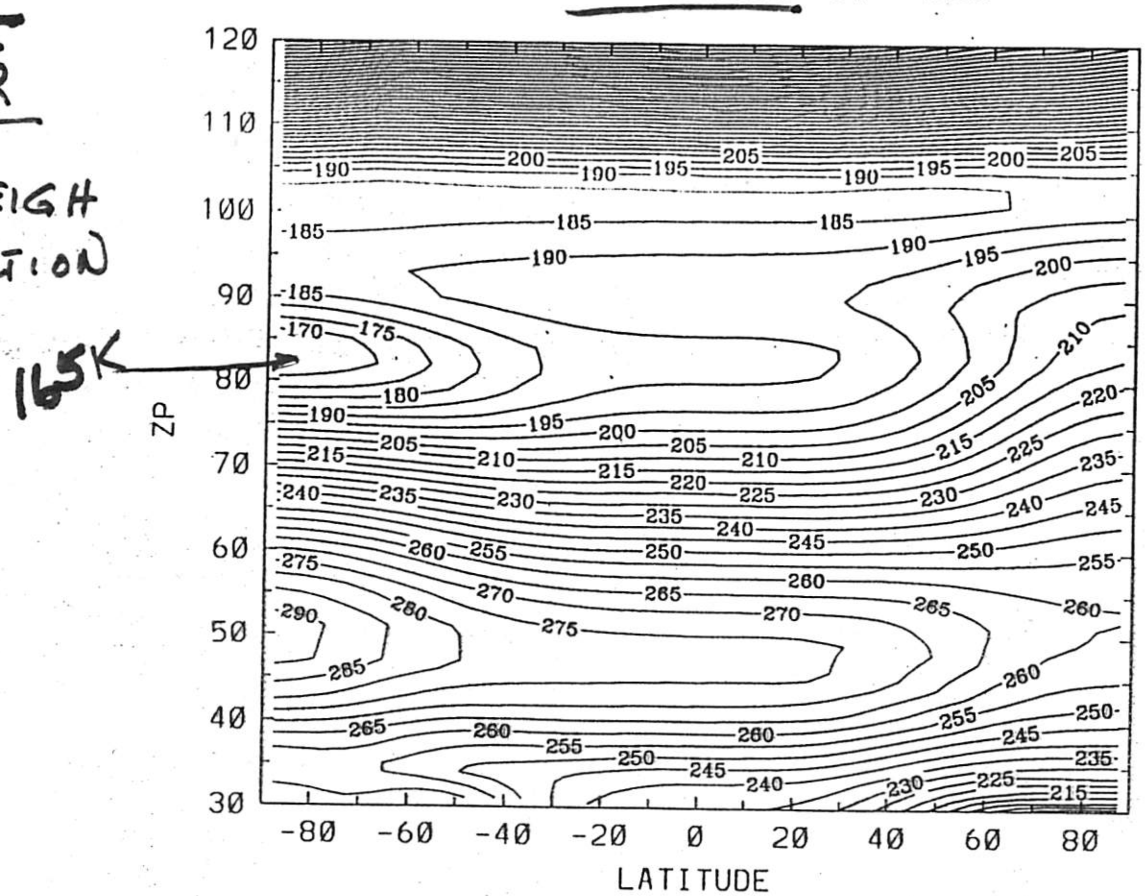
DEC. SOLSTICE

F_R

RAYLEIGH FRICTION

TN ZONAL MEANS UT= 0.00

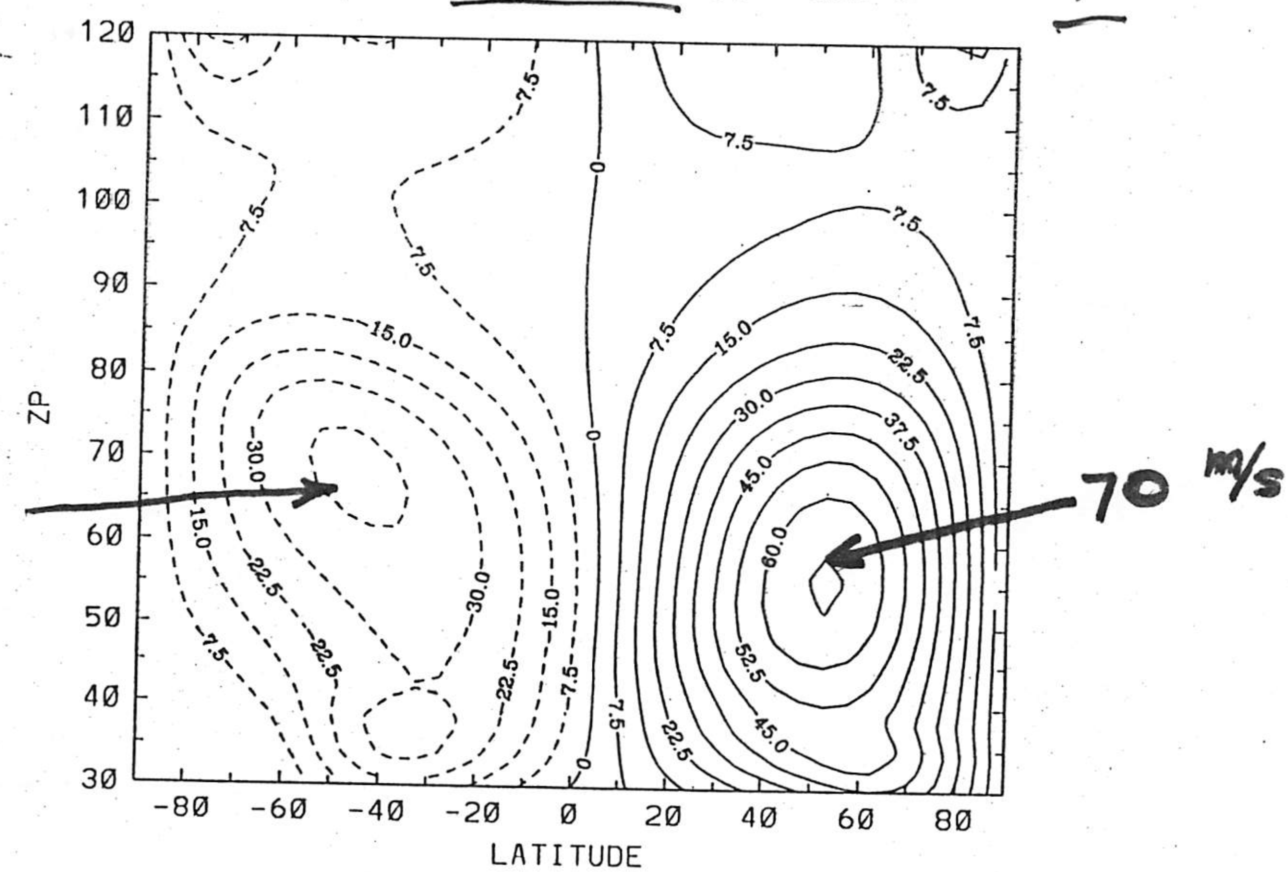
K



MINIMUM 165.2, MAXIMUM 352.8, CONTOUR INTERVAL 5

UN ZONAL MEANS UT= 0.00

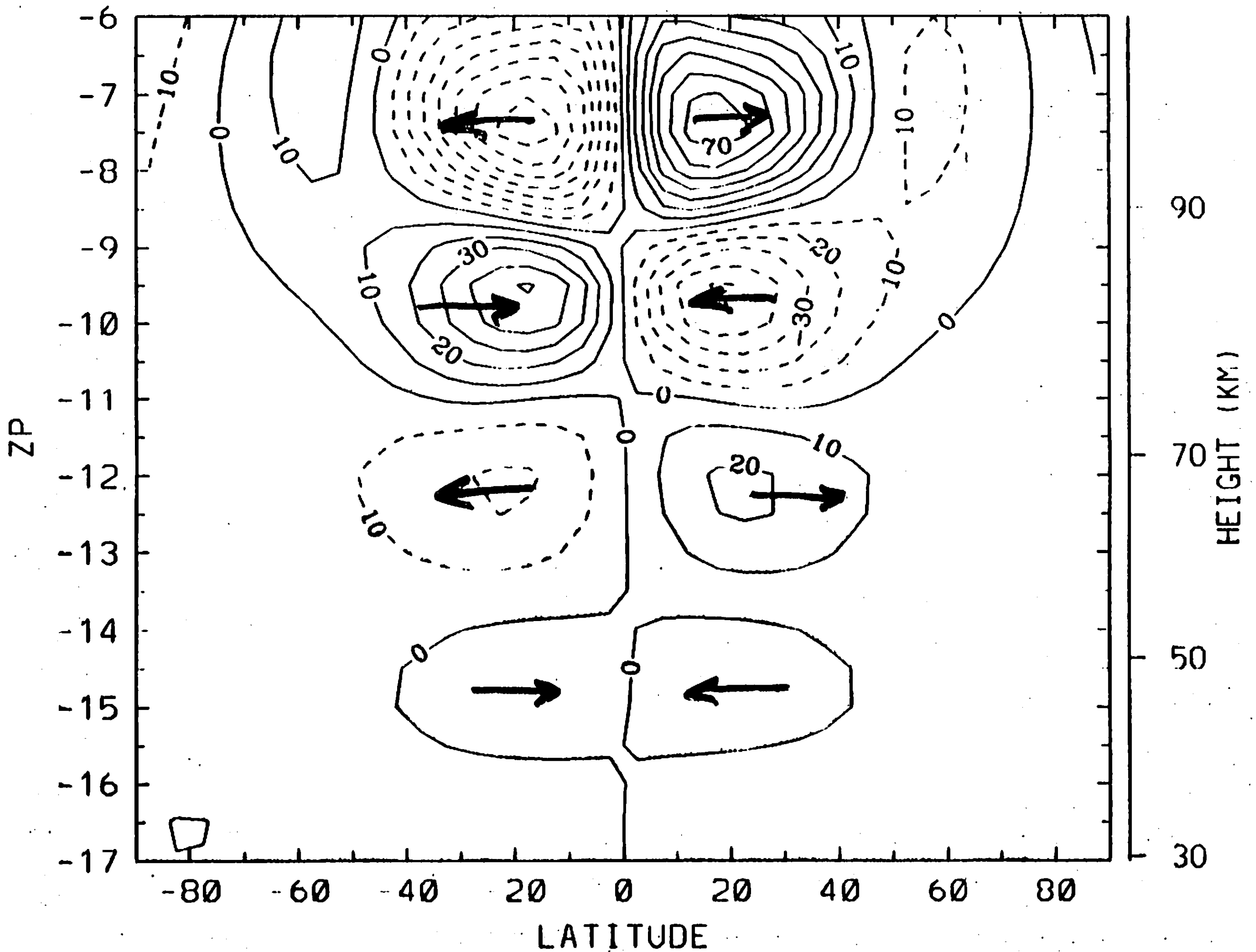
m/s



MIN −39.20, MAX 68.50, INTERVAL 7.5

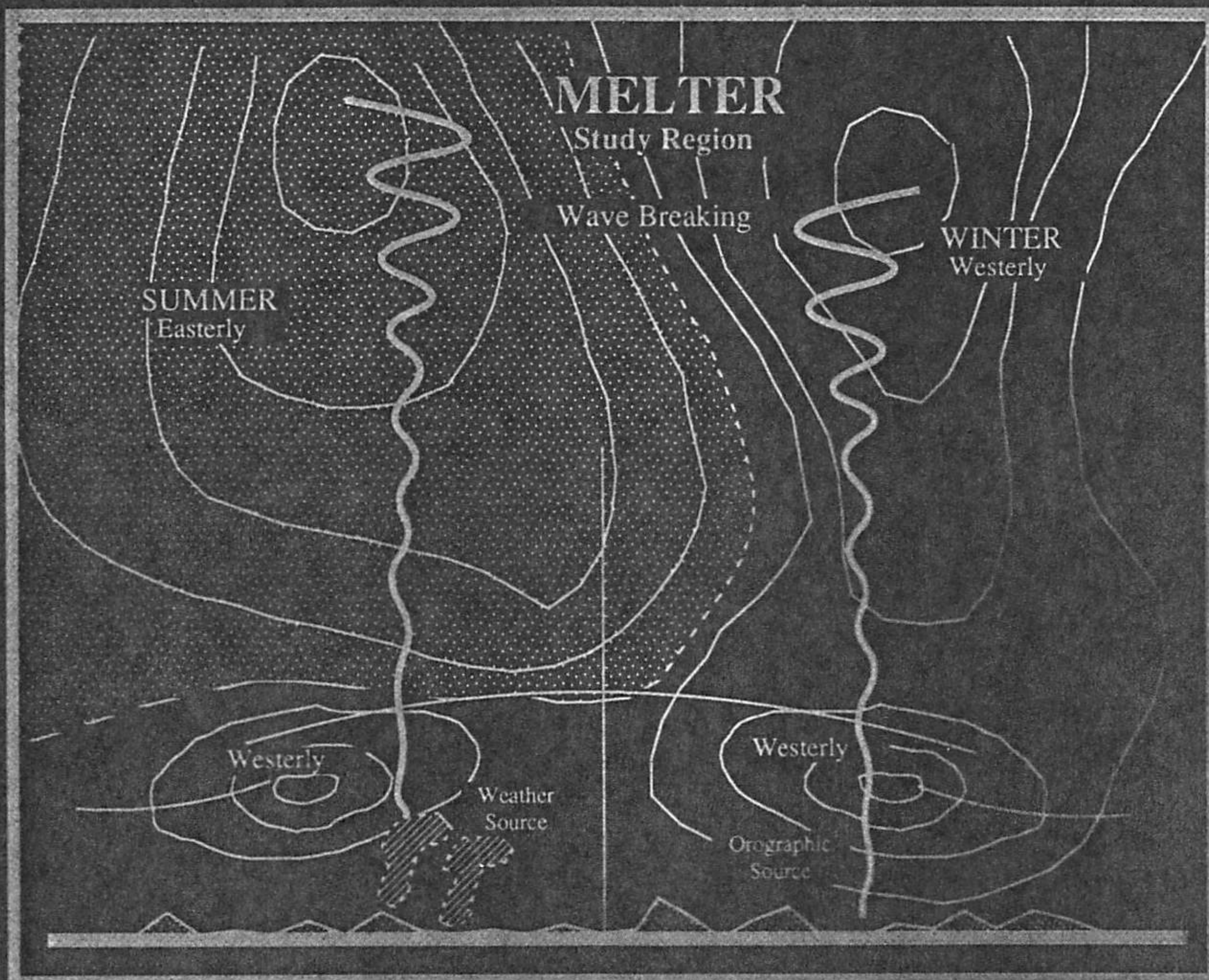
V (POSITIVE NORTHWARD)
(m/s)

VN LON- -180.00 UT- 0.00 NOON



MIN -76.24, MAX 77.43, INTERVAL 10

HISTORY=/ROBLE/RGR92/TISEZ3

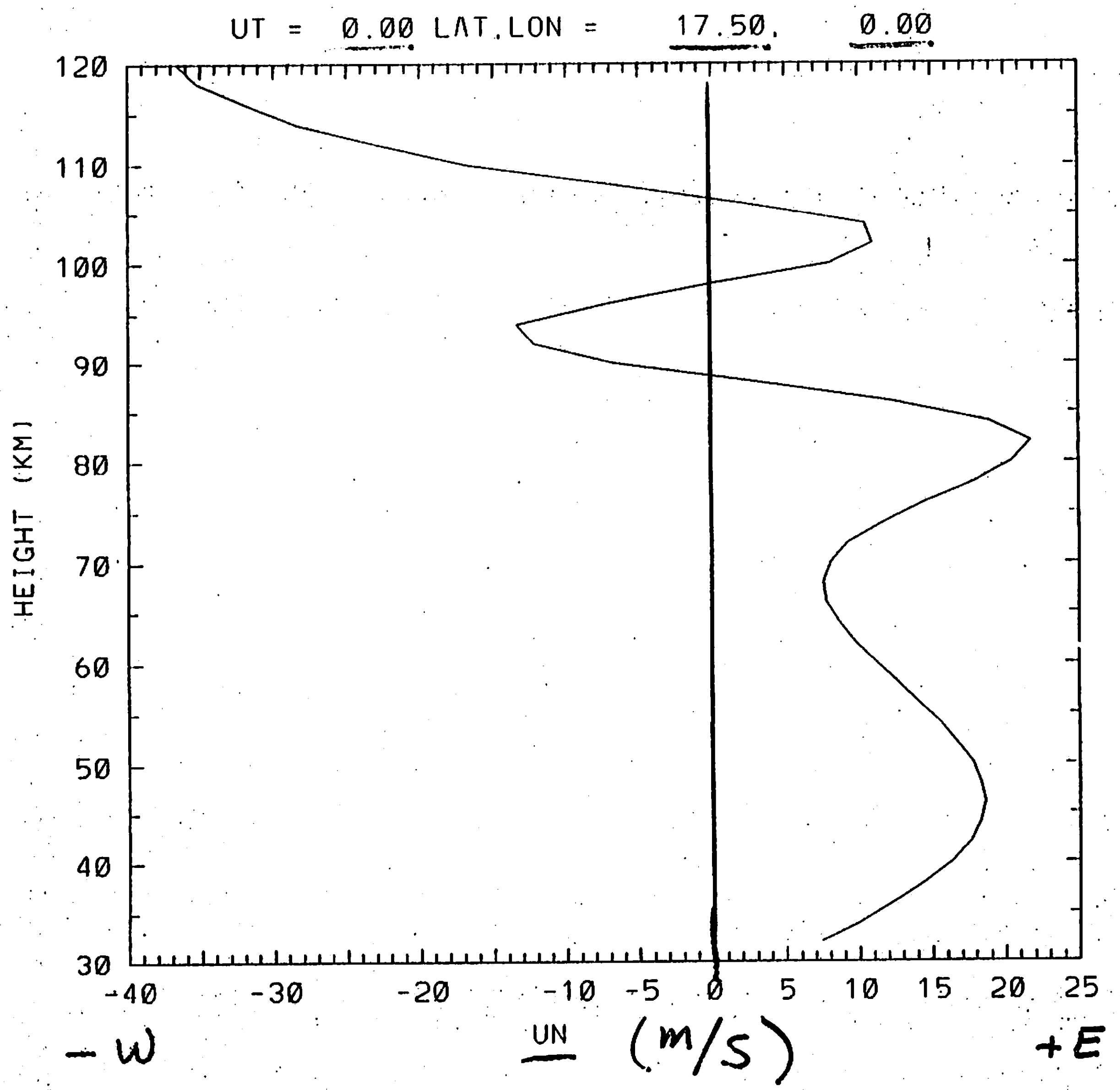


Gravity Wave Disturbances

Gravity Waves Propagate
If They Have The Correct Phase Speed.
Thus They Are Present Both In The Winterand Summer
Stratosphere And Mesosphere.

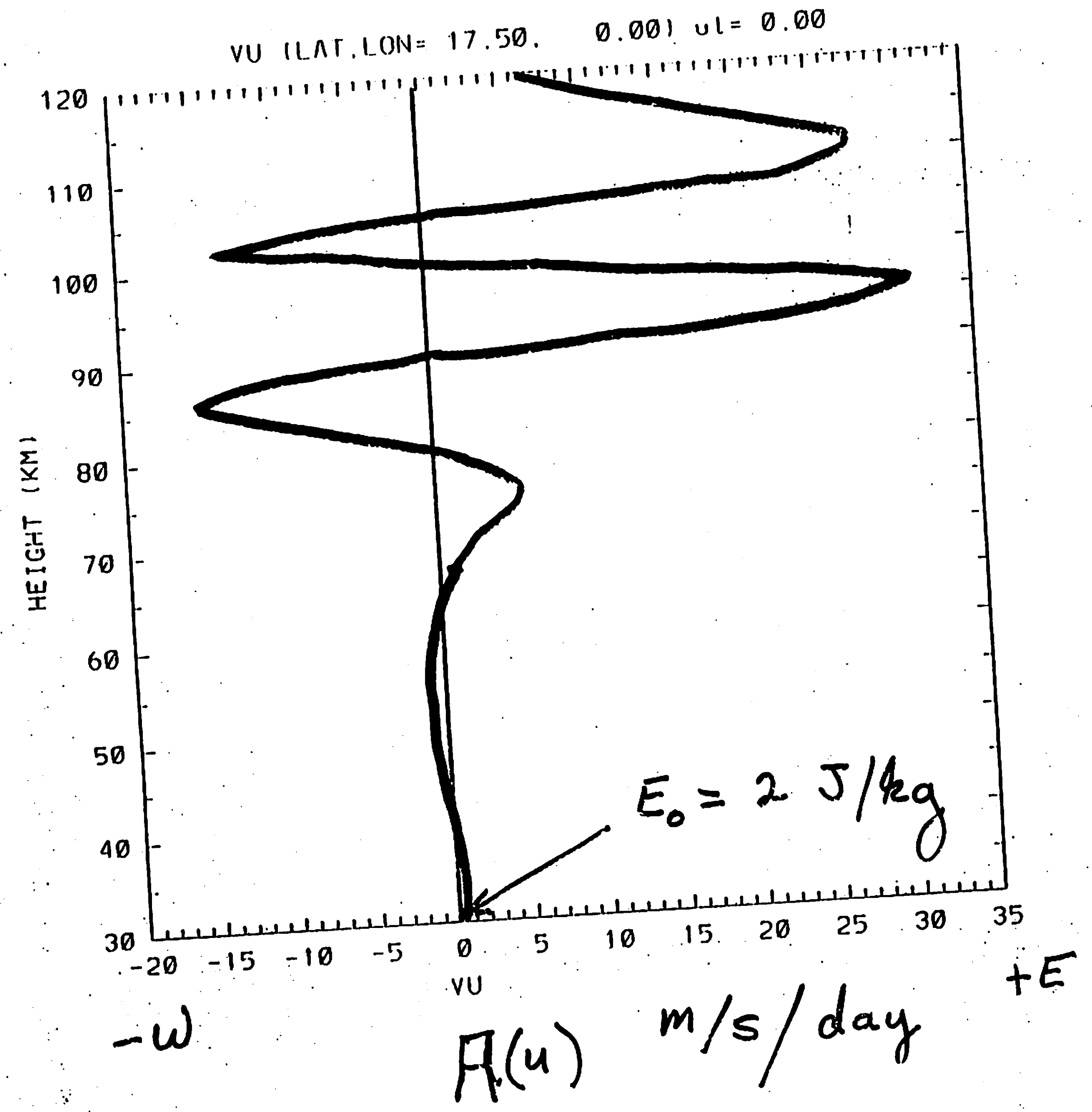
EQUINOX

ZONAL WIND



HISTORY=/ROBLE/RGR94/T15GAR3

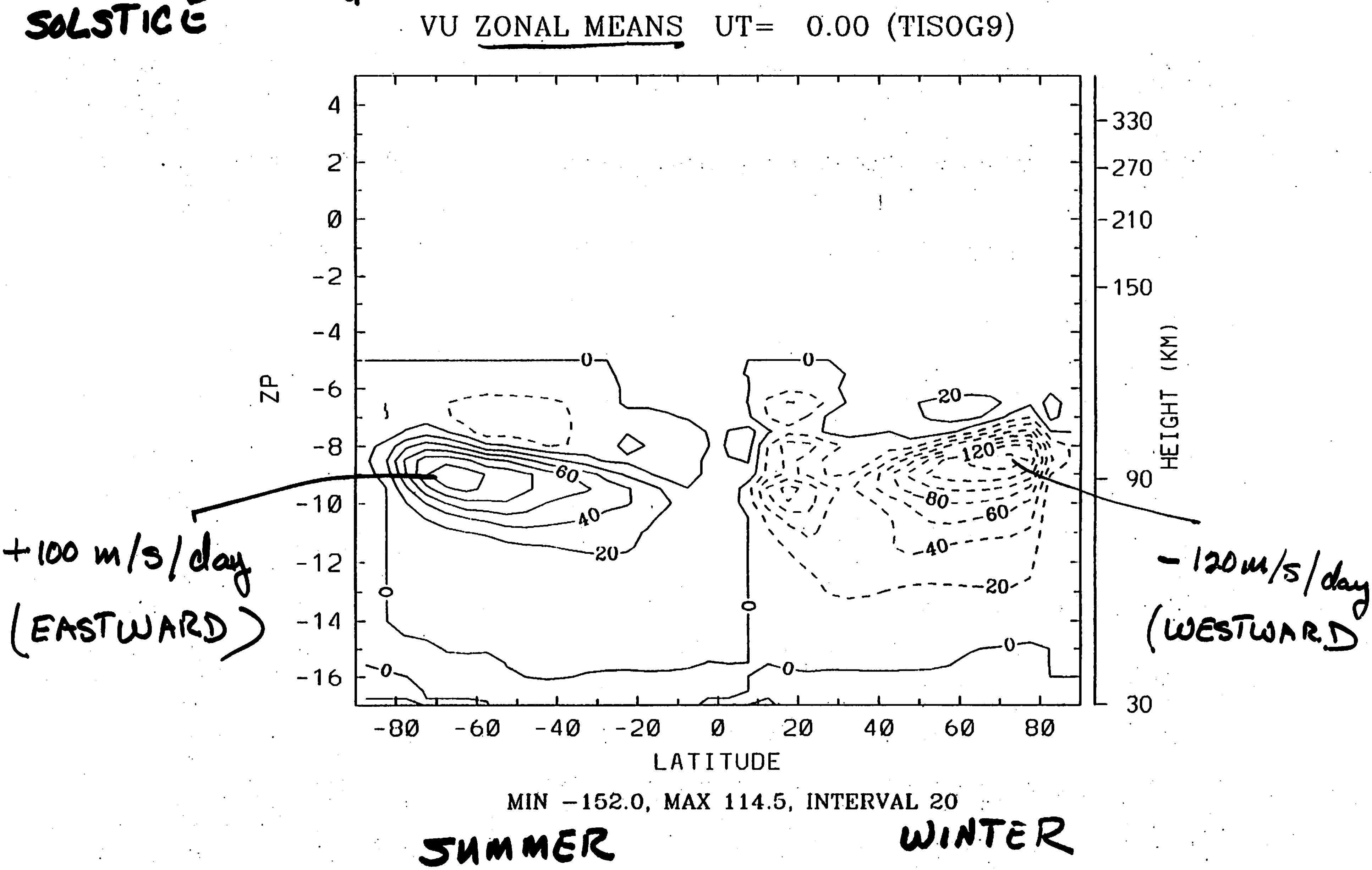
EQUINOX ZONAL WIND ACCELERATIO



GRAVITY WAVE DRAG (m/s/day)

DEC. SOLSTICE

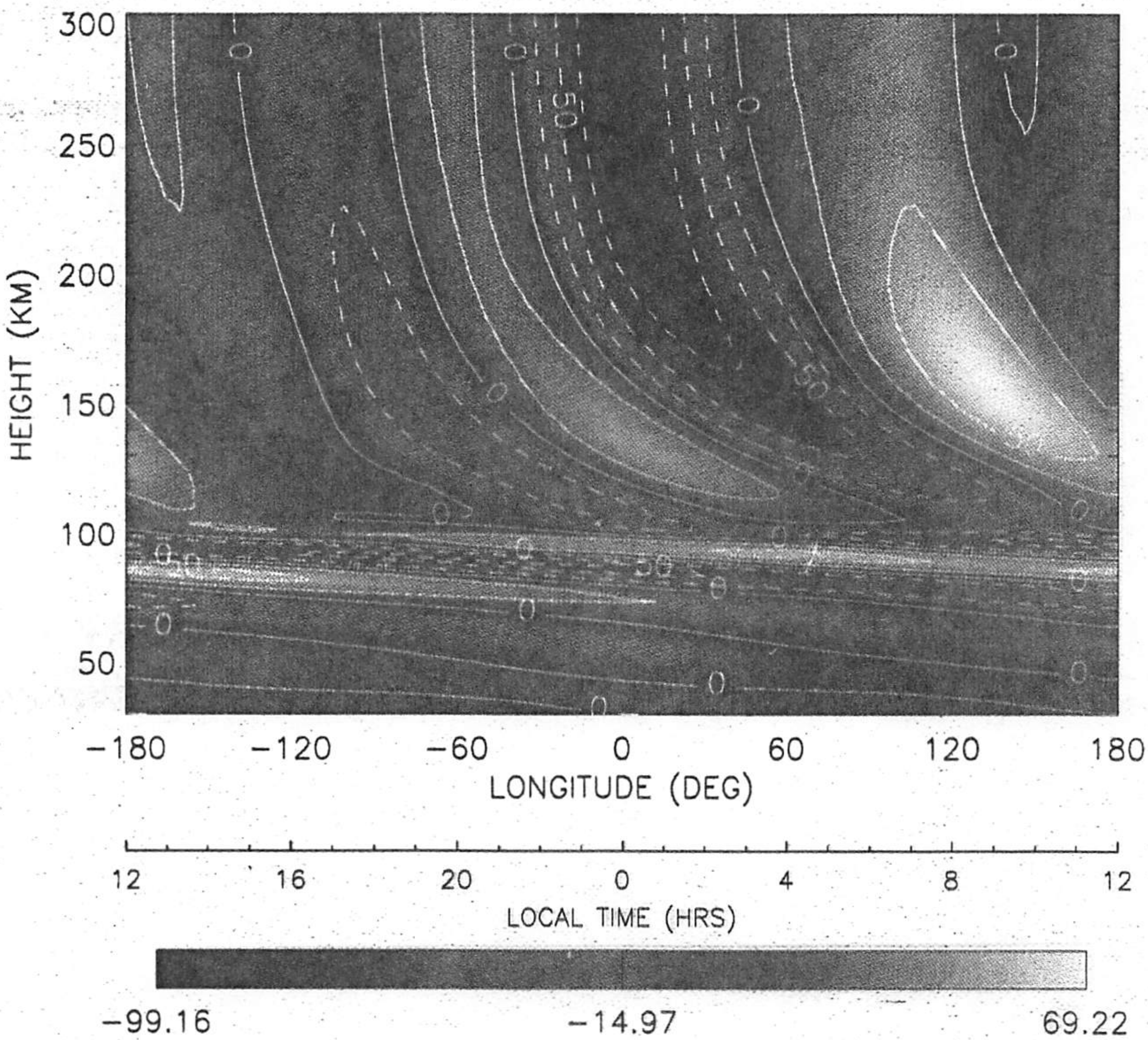
F_4



Vn (meridional wind m/s)

TIMESGCM VN

LAT = 17.5 UT = 0.0



CONTOUR -100. TO 100. BY 25.0 (MIN,MAX=-99.2,69.2)

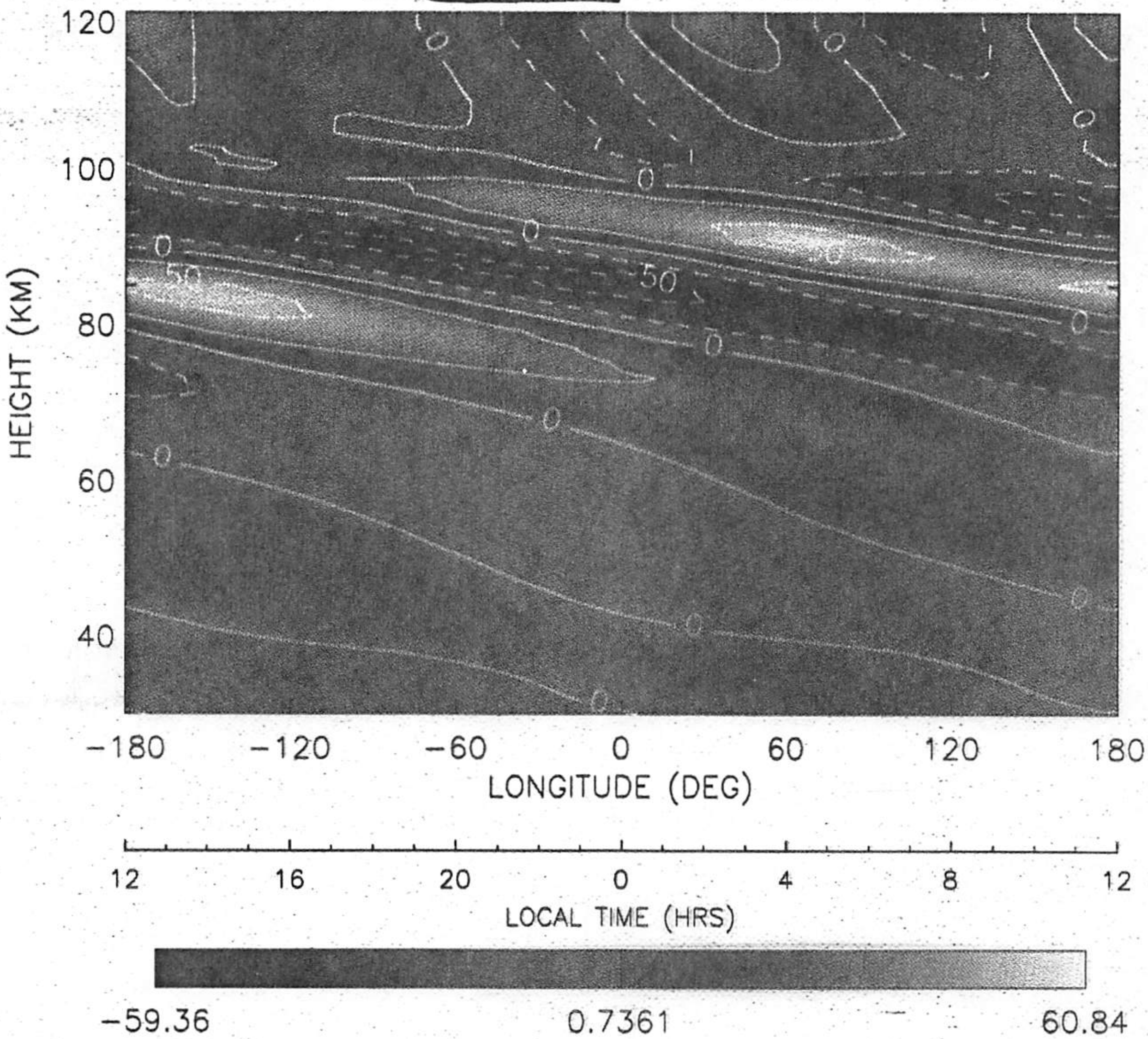
HISTORY /ROBLE/RGR93/TSEQBZ4 (6: 0: 0)

EQUINOX SMIN

V_n (meridional wind m/s)

TIMESGCM VN

LAT = 17.5 UT = 0.0



CONTOUR −100. TO 100. BY 25.0 (MIN,MAX=−59.4,60.8)

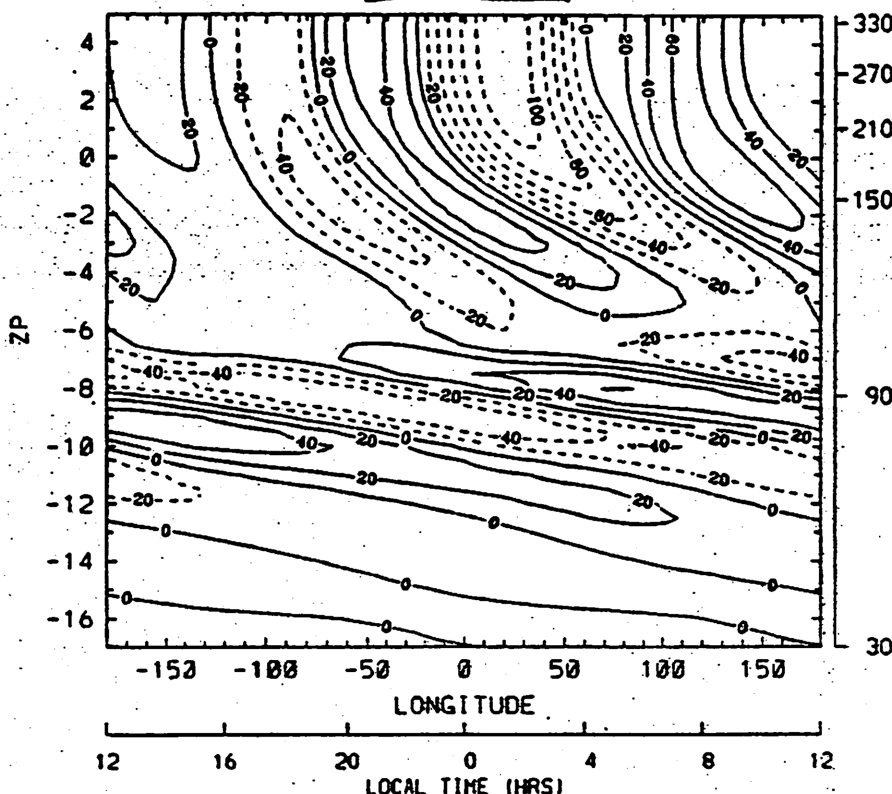
HISTORY /ROBLE/RGR93/TSEQBZ4 (6: 0: 0)

EQUINOX SOLAR MIN.

WEAK G.W. SOURCE

2 J/kg.

VN LAT= 17.50 UT= 0.00



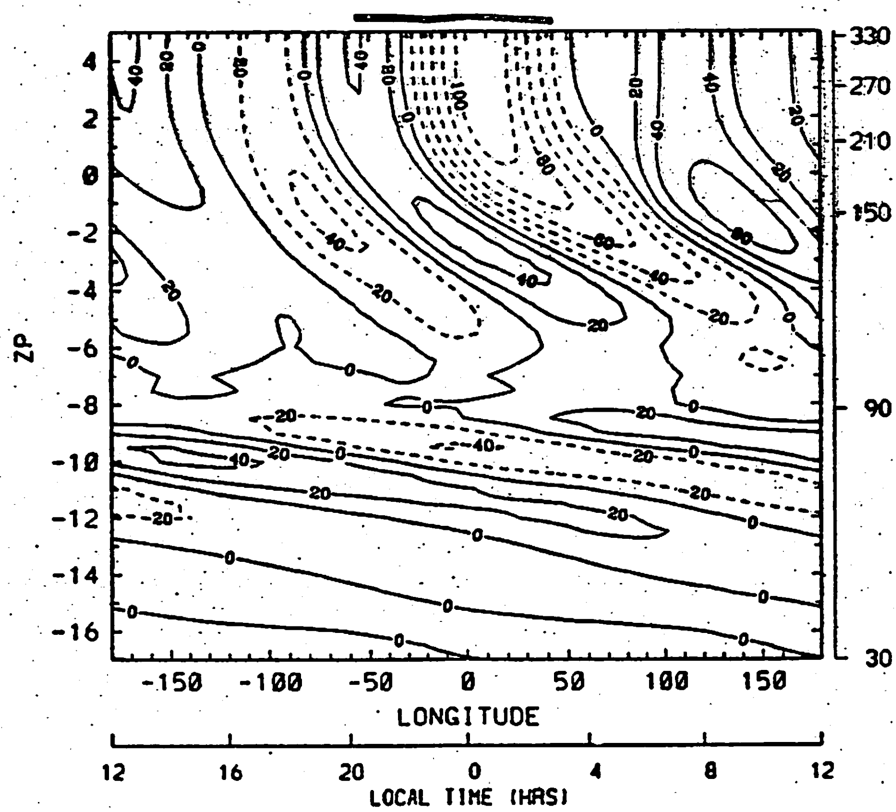
damp 105 km

(a) MINIMUM −117.1, MAXIMUM 75.3, CONTOUR INTERVAL 20

Strong G.W. SOURCE

4 J/kg.

VN LAT= 17.50 UT= 0.00



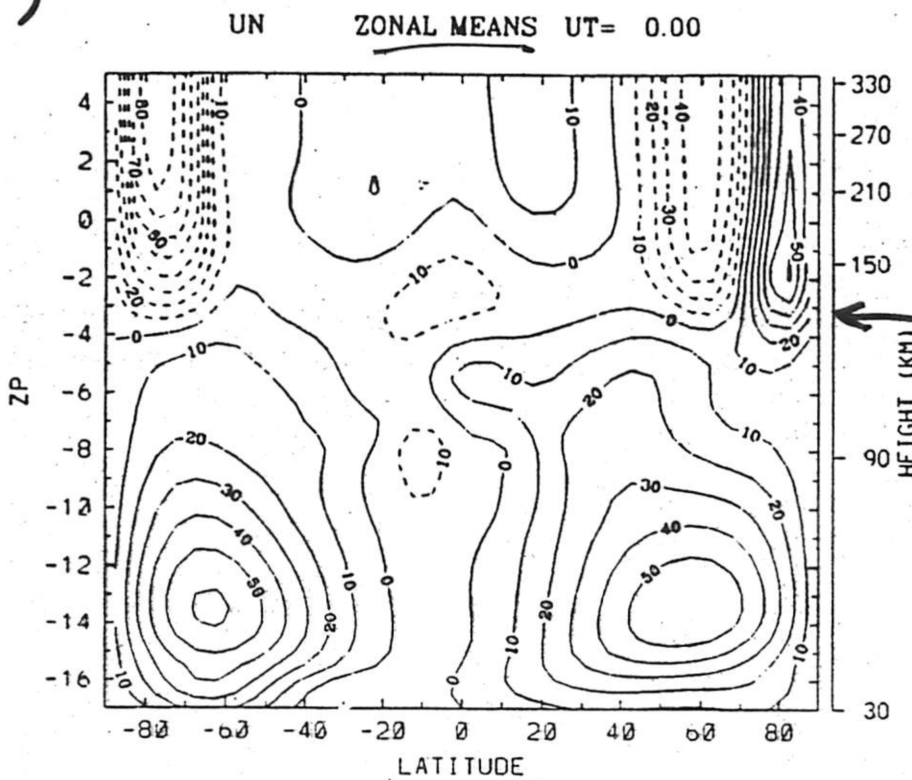
damp 90 km

(b) MINIMUM −119.0, MAXIMUM 74.0, CONTOUR INTERVAL 20

U_n ZONAL MEAN (m/s) EQUINOX SOLAR MIN.

WEAK G.W. SOURCE

2 J/kg.

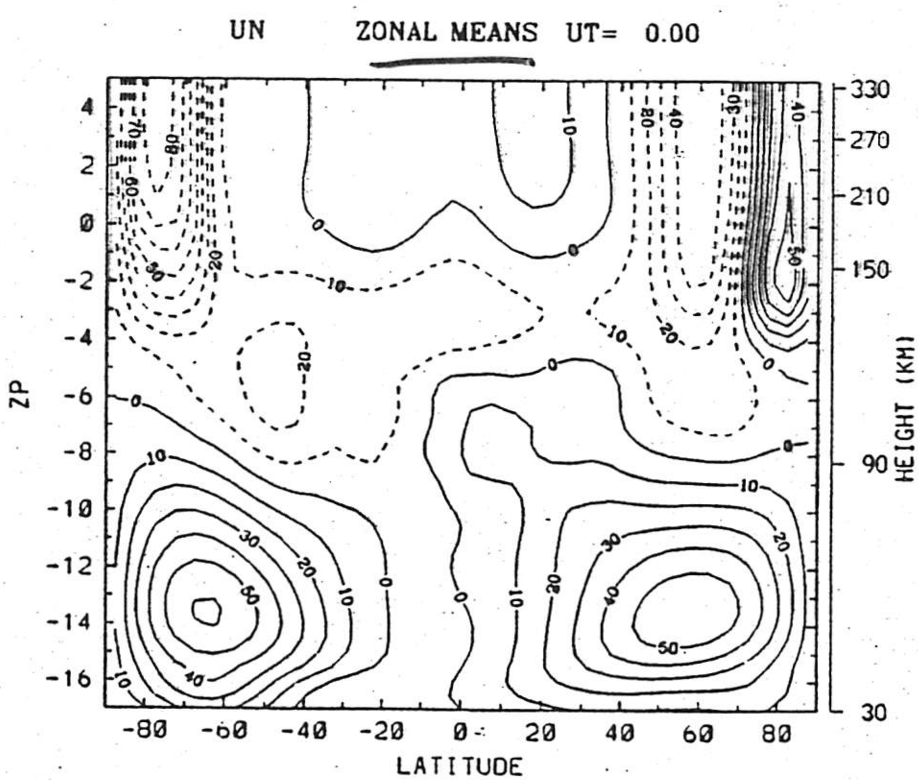


REVERSAL 140 KM

(c) MINIMUM -88.13, MAXIMUM 62.00, CONTOUR INTERVAL 10

Strong G.W. SOURCE

4 J/kg.



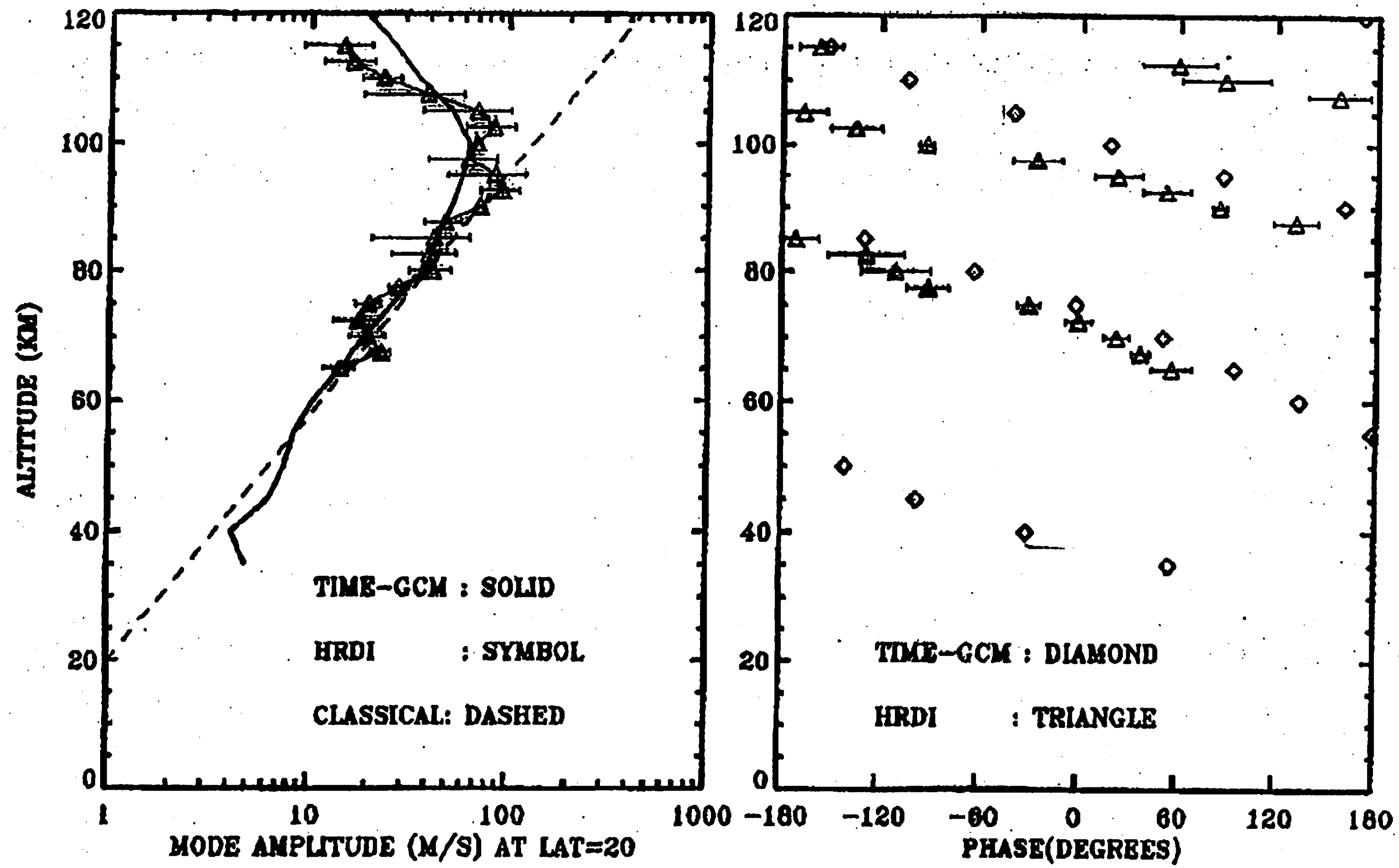
REVERSAL 95 KM

(d) MINIMUM -87.22, MAXIMUM 61.20, CONTOUR INTERVAL 10

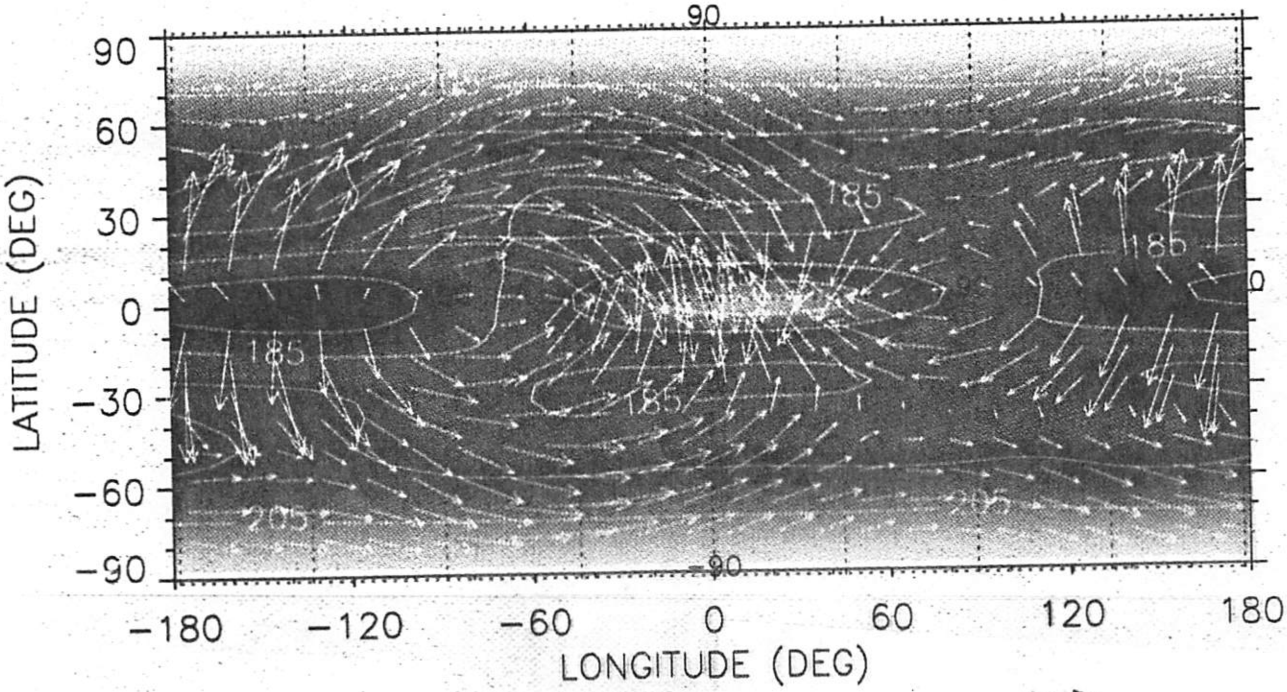
D Wu - U. of Michigan

(2)

DIURNAL (1,1) TIDE AT SPRING EQUINOX
(MERIDIONAL COMPONENT)

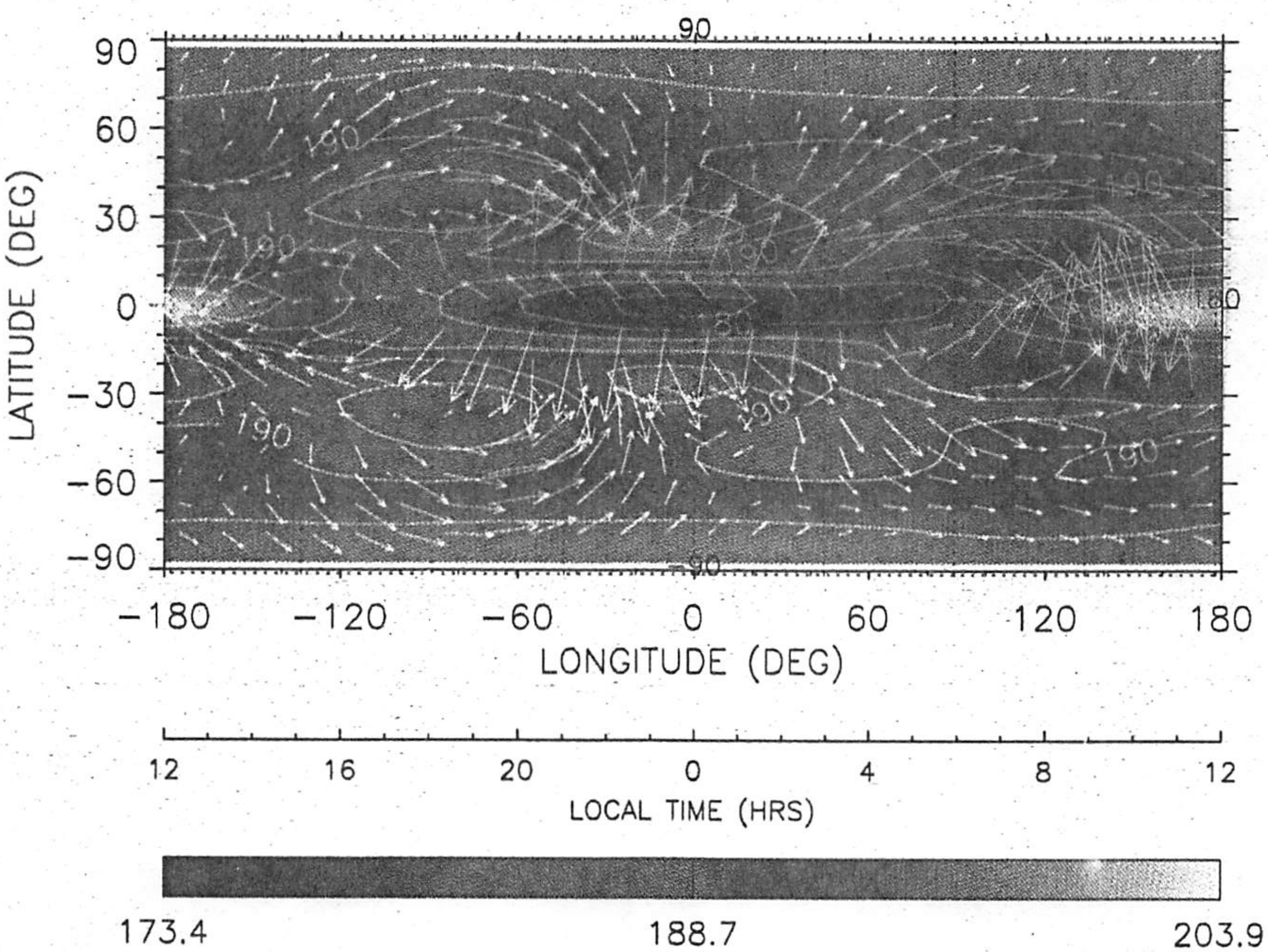


TIMESGCM TN (UN+VN) ZP = −9.0 UT = 0.0



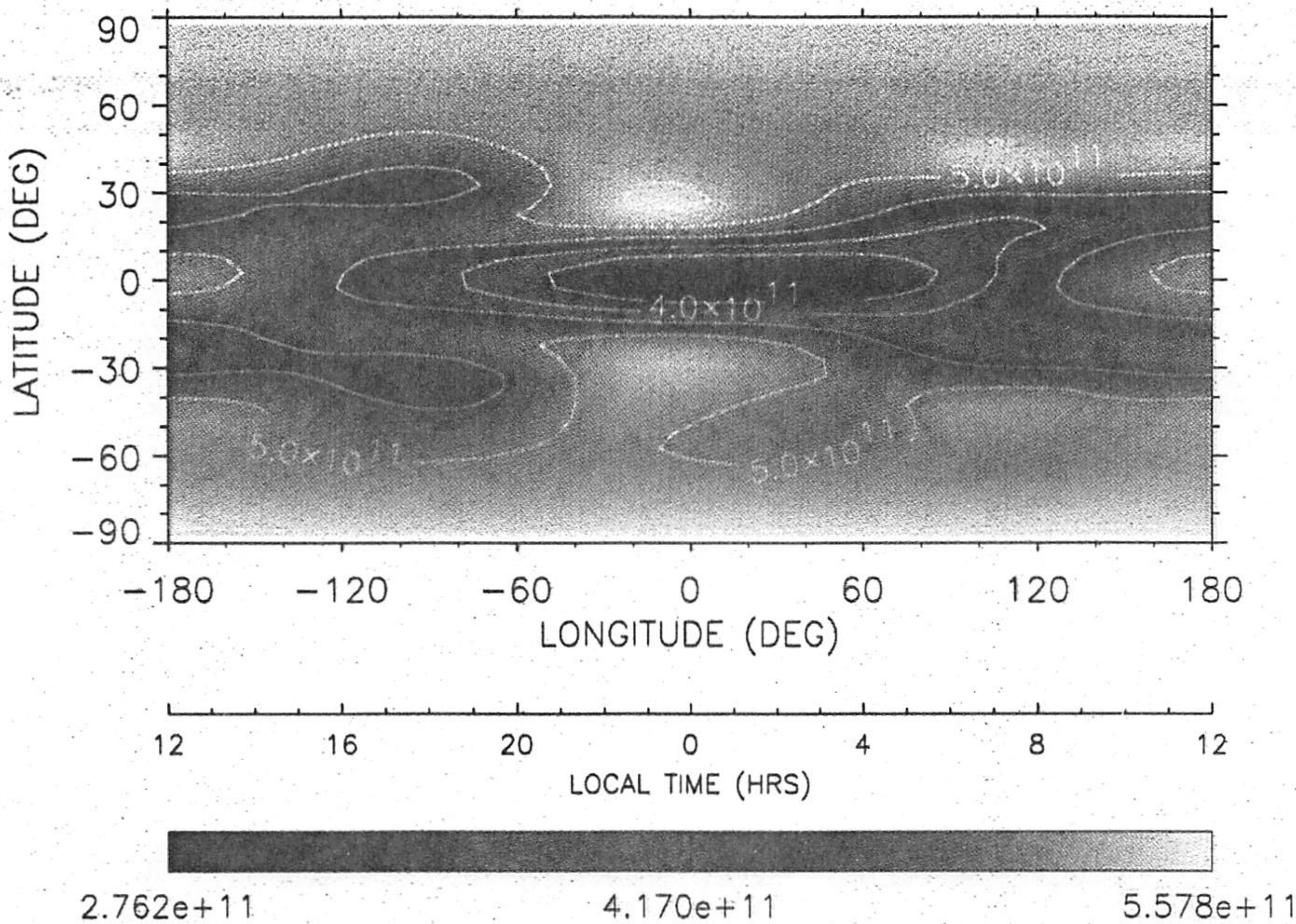
95 Km T_n, $\vec{V}_n$

TIMESGCM TN (UN+VN) ZP = −7.0 UT = 0.0



97 Km $n(O, cm^{-3})$

TIMESGCM O1   HT = 97.0   UT = 0.0



CONTOUR 3.00E+11 TO 6.00E+11 BY 5.00E+10 (MIN,MAX=2.76E+11,5.58E+11)

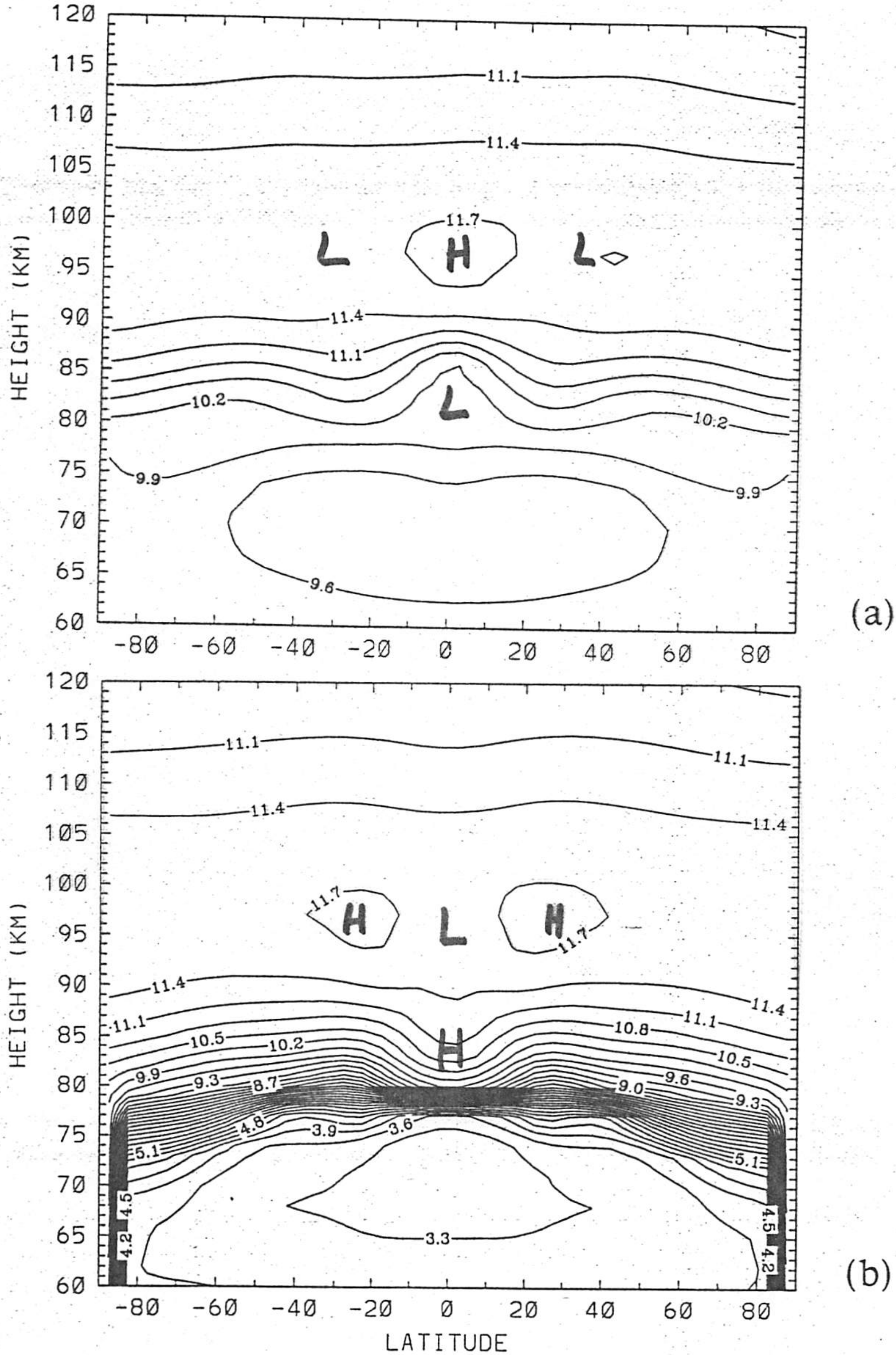
HISTORY /ROBLE/RGR93/TSEQBZ4 (6: 0: 0)

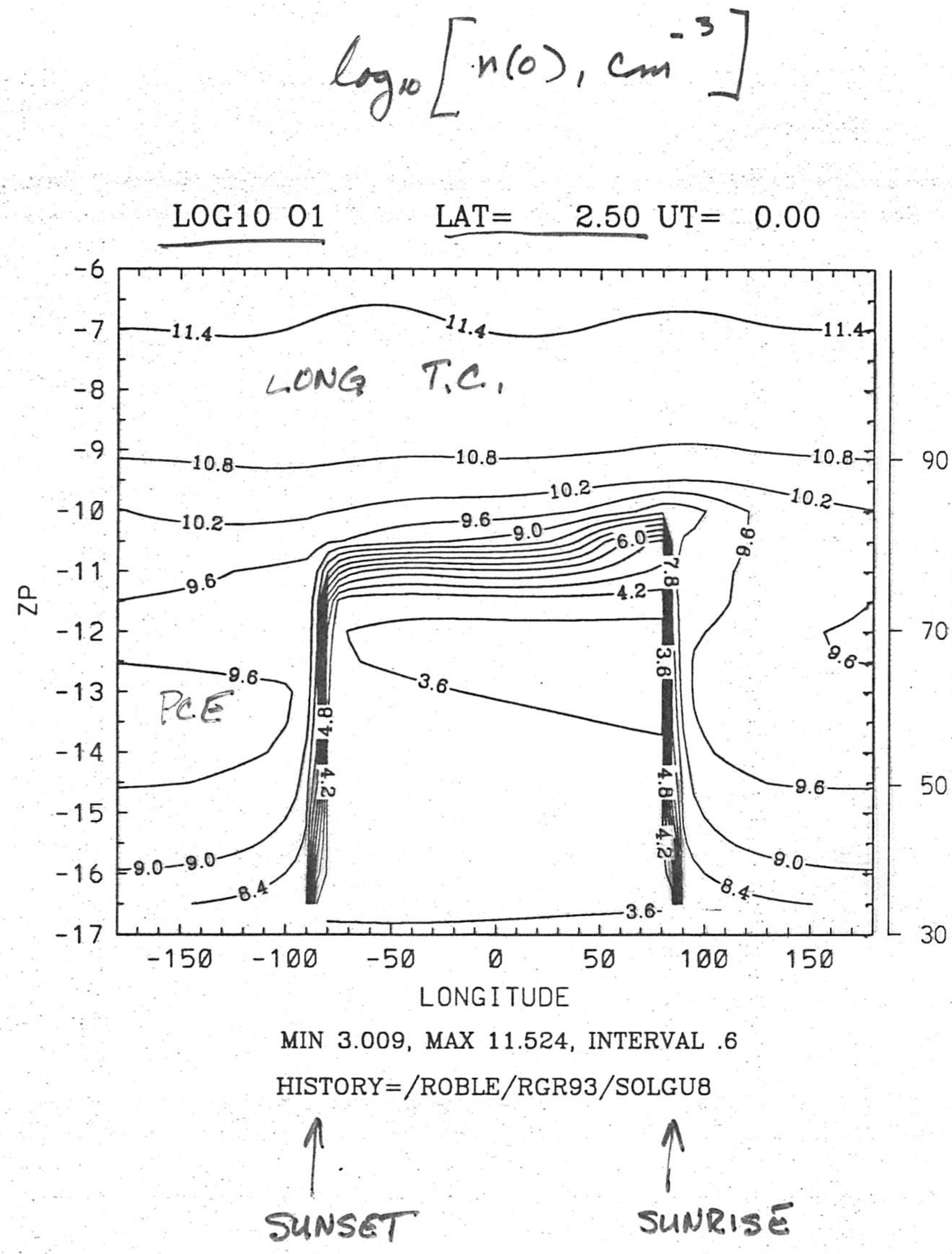
ATOMIC OXYGEN

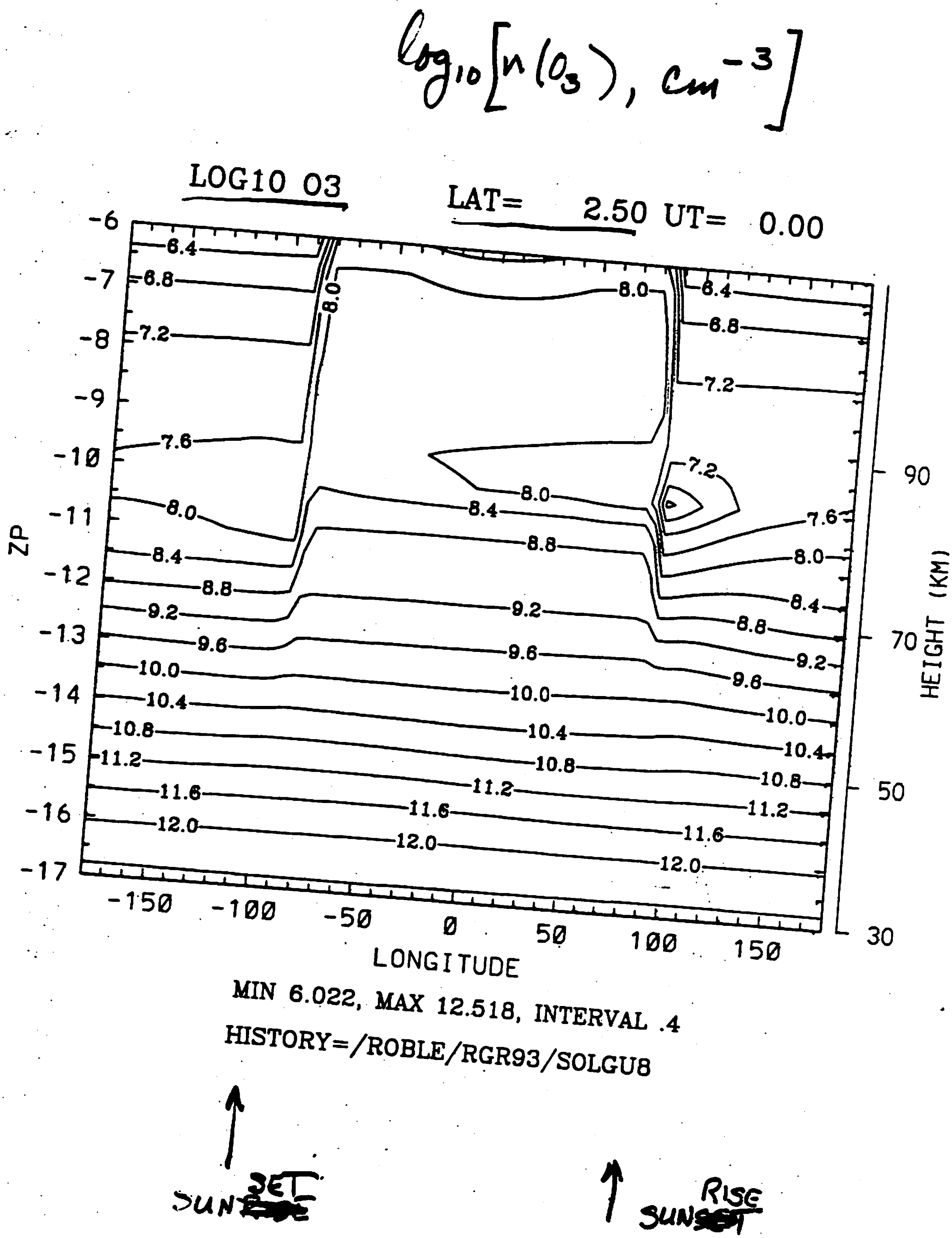
LOG$_{10}$ [n(O); cm^{-3}]

NOON

MIDNIGHT



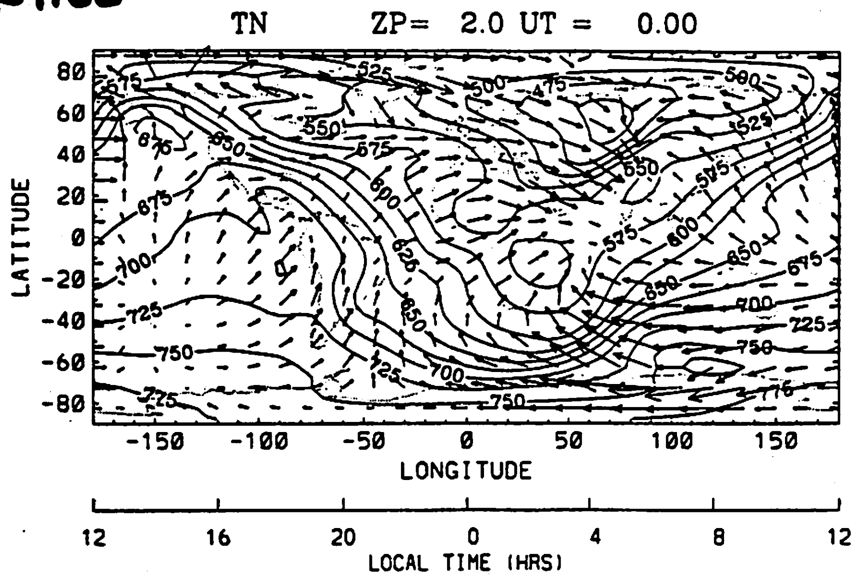

log10 [n(O), cm^-3]
LOG10 O1 LAT= 2.50 UT= 0.00
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
ZP
11.4
11.4
11.4
LONG T.C.
10.8
10.8
10.8
10.2
10.2
10.2
9.6
9.0
6.0
7.8
9.6
9.6
4.2
3.6
9.6
9.6
3.6
PCE
4.8
4.2
4.8
4.2
9.6
9.0
9.0
9.0
8.4
8.4
3.6
90
70
50
30
HEIGHT (KM)
-150
-100
-50
0
50
100
150
LONGITUDE
MIN 3.009, MAX 11.524, INTERVAL .6
HISTORY=/ROBLE/RGR93/SOLGU8
SUNSET
SUNRISE


log10[n(O3), cm-3]
LOG10 O3
LAT= 2.50 UT= 0.00
ZP
HEIGHT (KM)
LONGITUDE
MIN 6.022, MAX 12.518, INTERVAL .4
HISTORY=/ROBLE/RGR93/SOLGU8
SUNSET
SUNRISE

DEC. SOLSTICE

+ DIURNAL TIDE

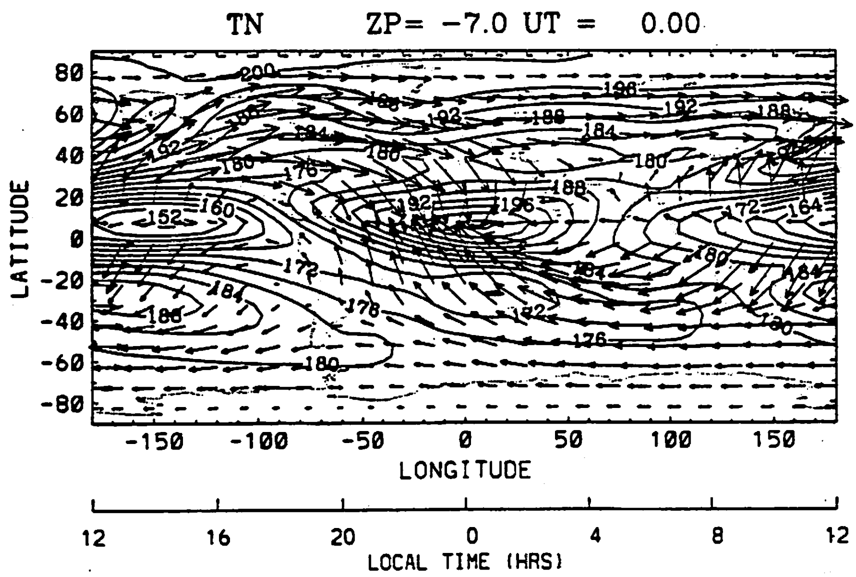
~300 KM



MIN 437.8, MAX 787.5, INTERVAL 25

HISTORY=/ROBLE/RGR92/TISSZ4 340 M/S

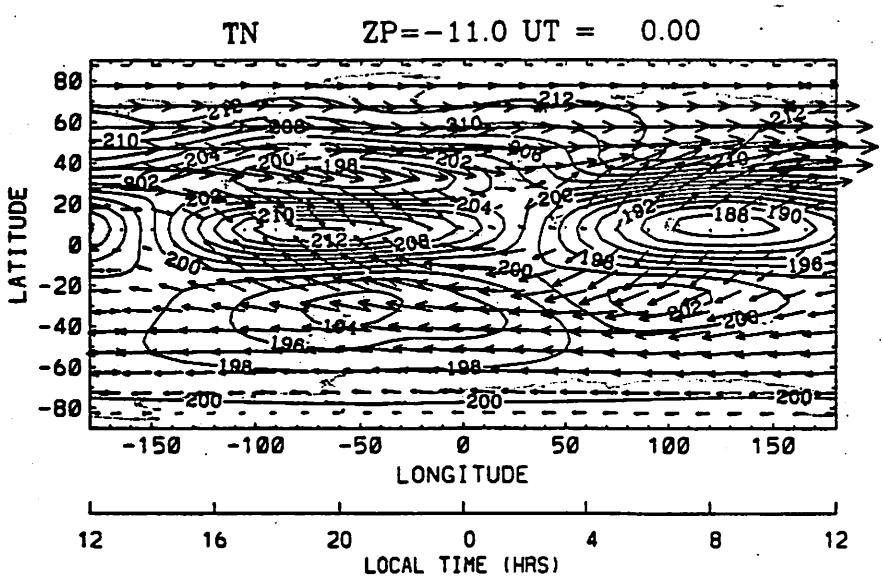
~90 KM



MIN 150.63, MAX 204.52, INTERVAL 4

HISTORY=/ROBLE/RGR92/TISSZ4 155 M/S

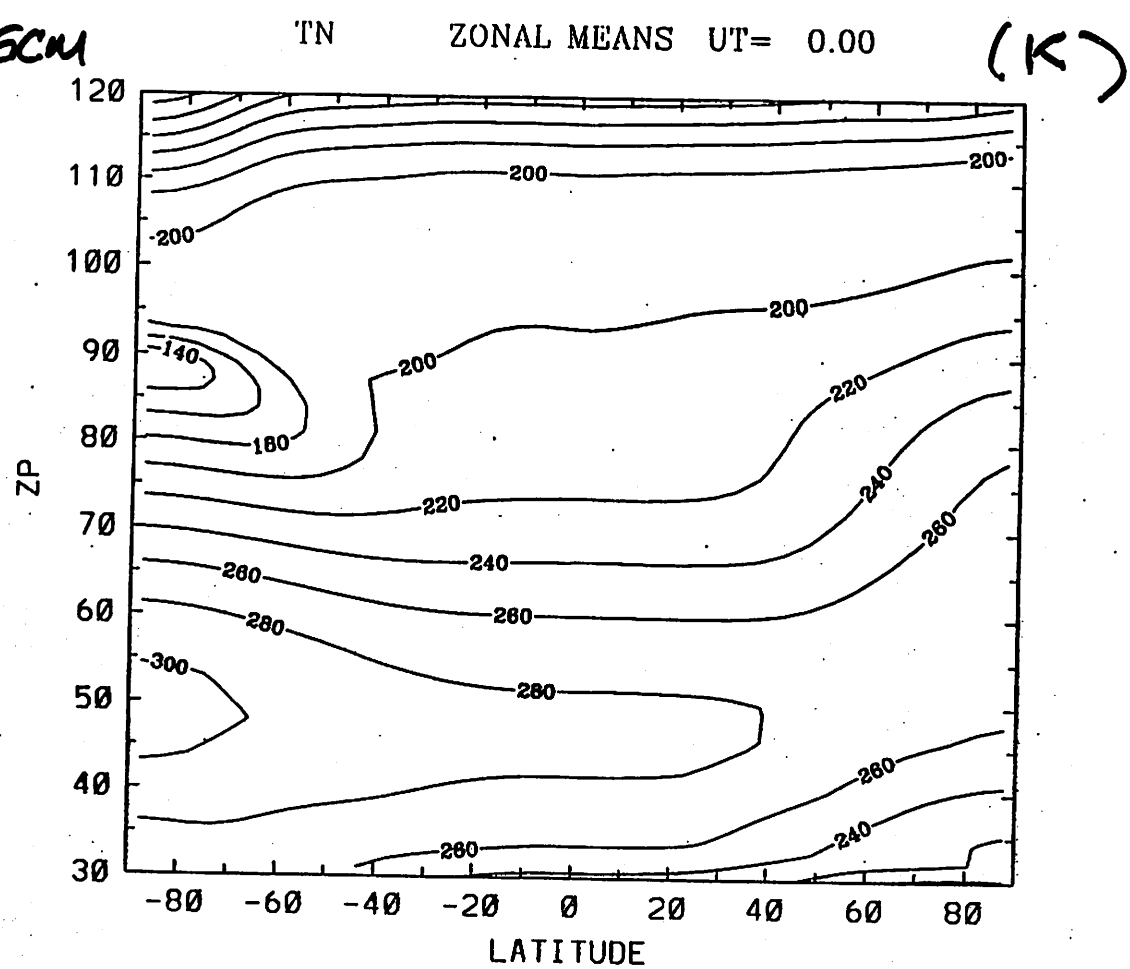
~70 KM



MIN 187.00, MAX 214.21, INTERVAL 2

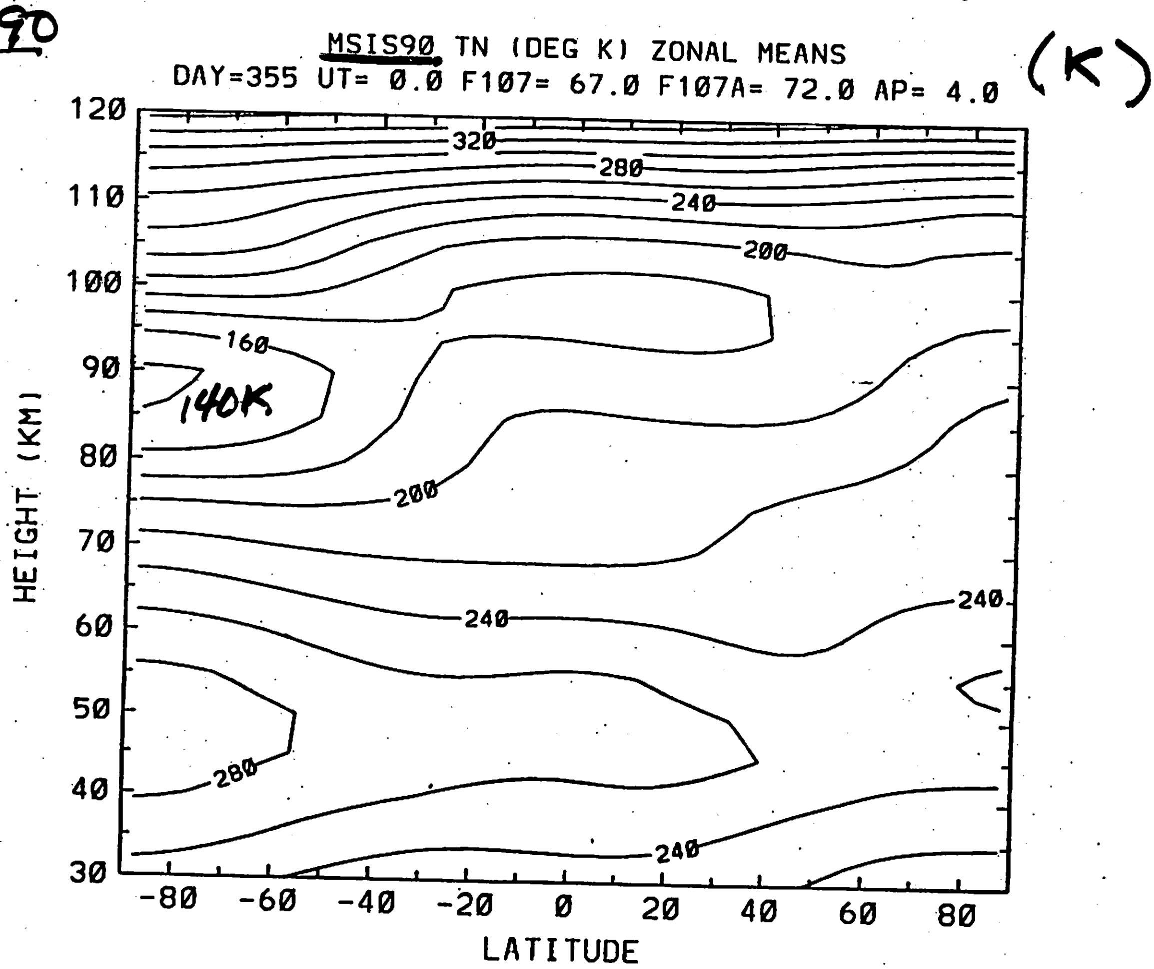
HISTORY=/ROBLE/RGR92/TISSZ4 130 M/S

TIME-GCM



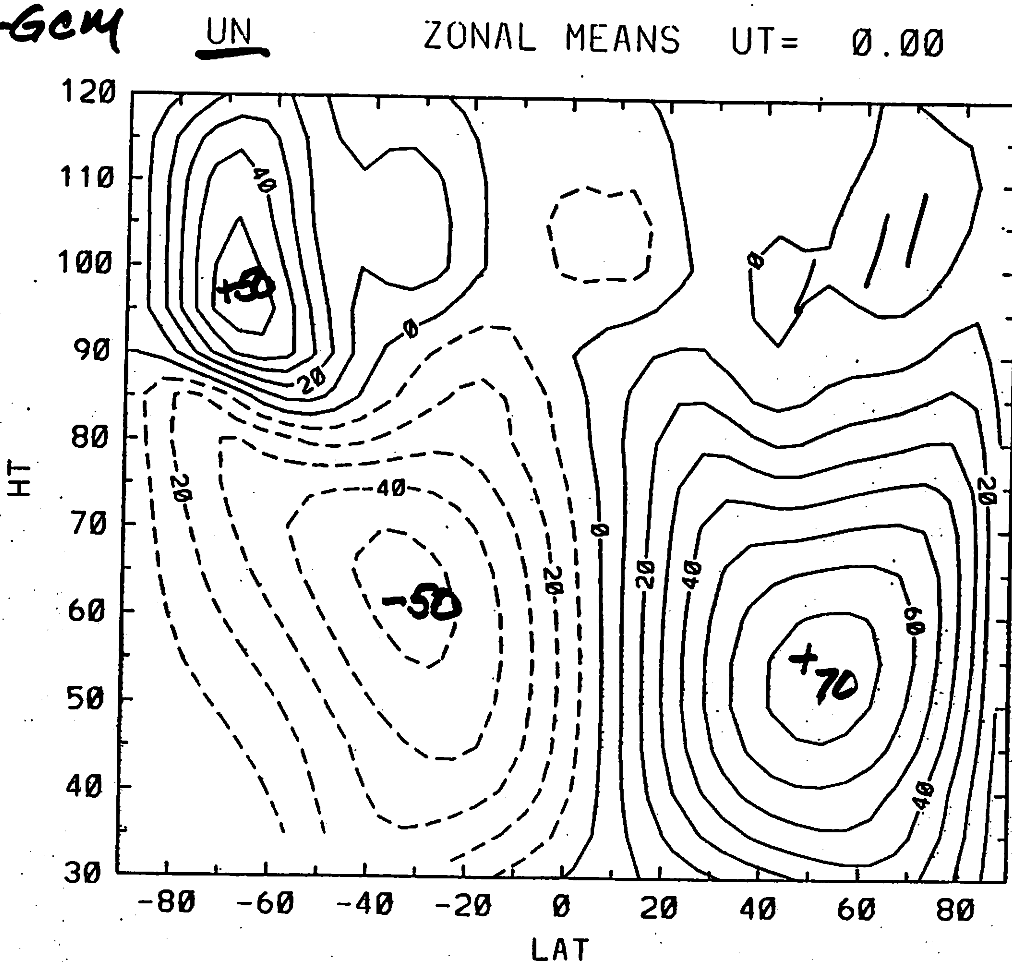
MINIMUM 120.3, MAXIMUM 332.6, CONTOUR INTERVAL 20

MSIS-90



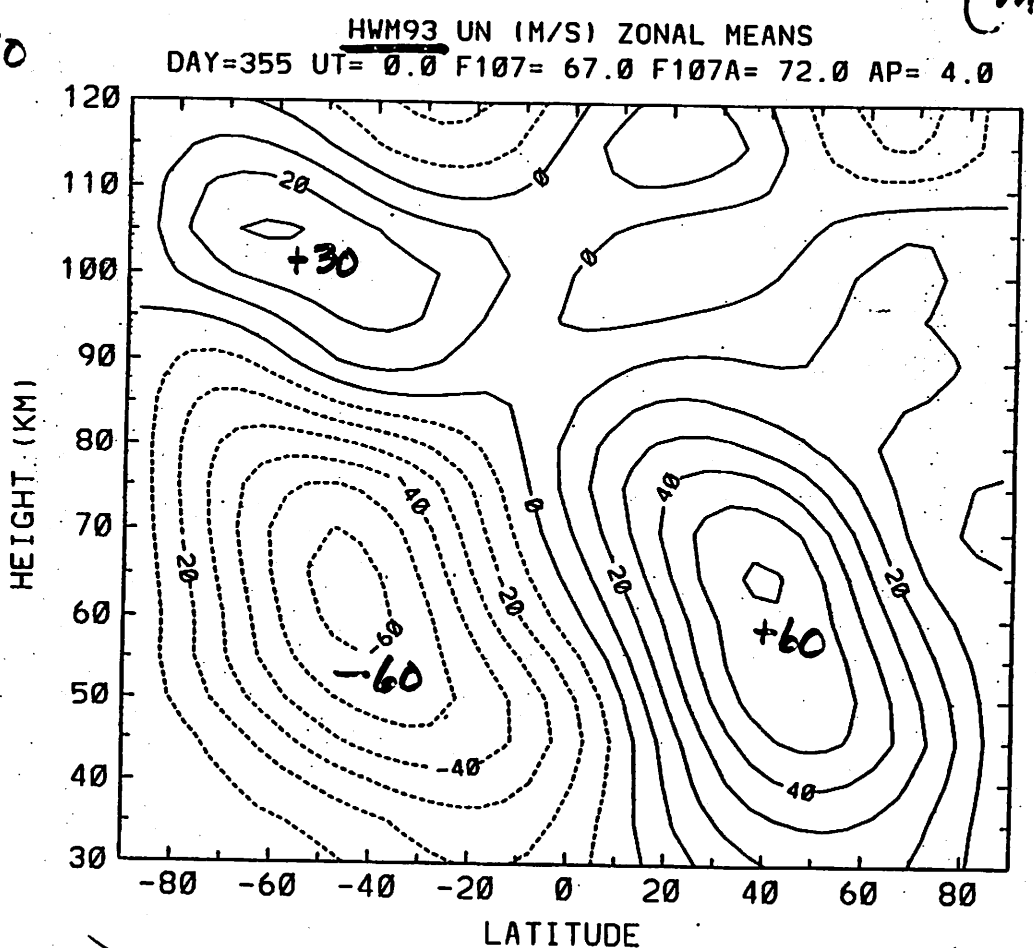
MIN 137.4, MAX 367.3, INT 20

TIME-GCM (m/s)



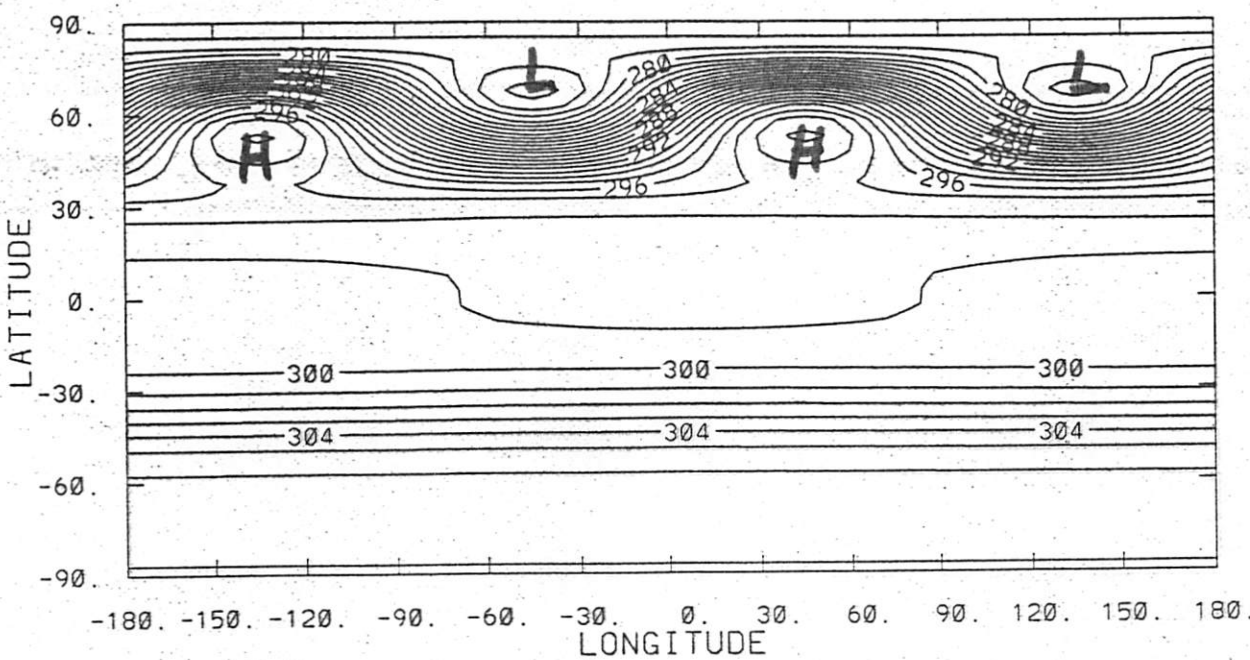
MIN -53.56, MAX 75.90, INT 10

MSIS-90 (m/s)

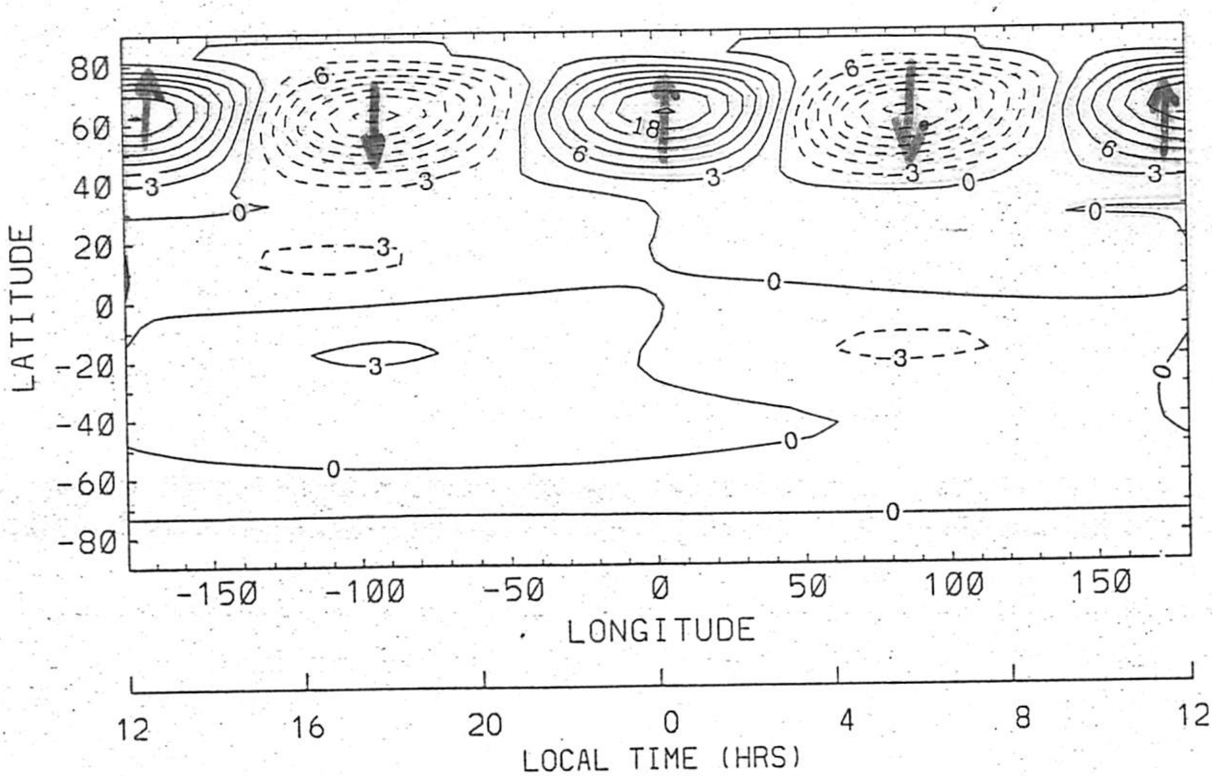


MIN -63.42, MAX 61.38, INT 10

GEOPOTENTIAL (10mb, 30Km)



MERIDIONAL WIND (m/s) [10mb, 30Km)



MIN −21.90, MAX 21.21, INTERVAL 3

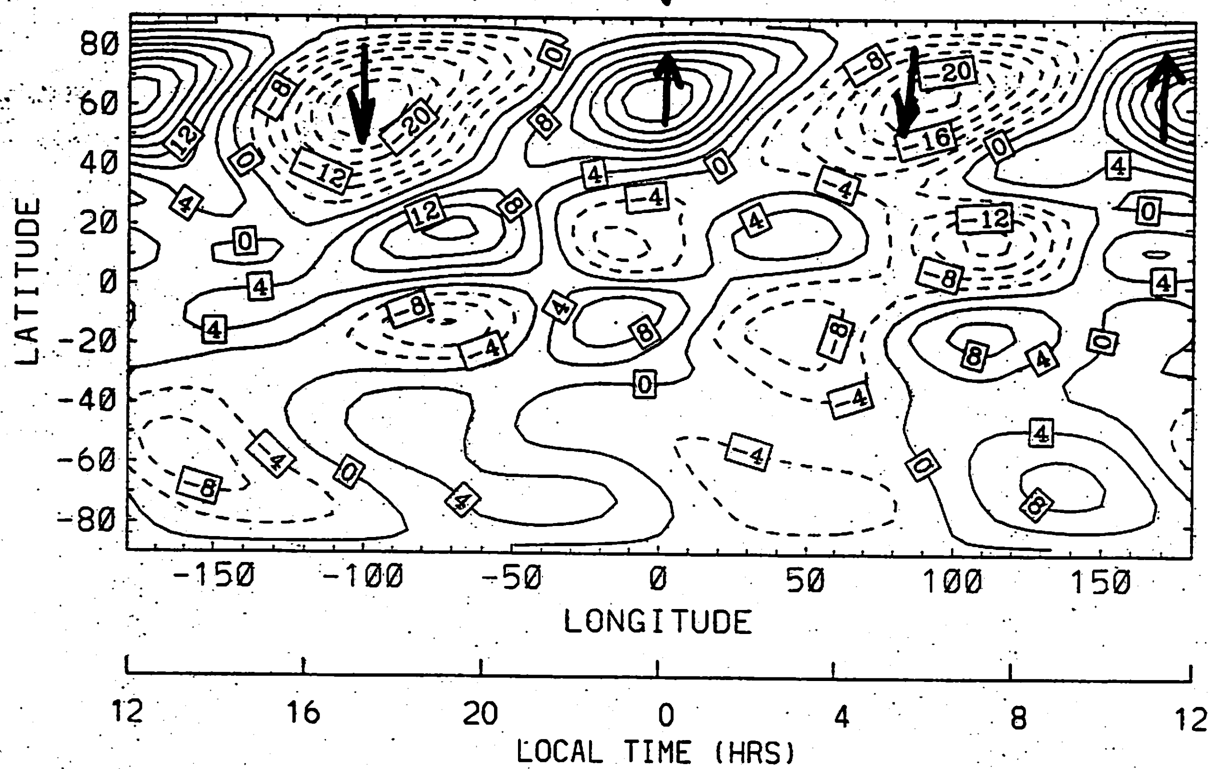
MERIDIONAL WIND (m/s)

VN

RAW DIFFERENCE FIELD

ZP= −7.0 UT= 0.00

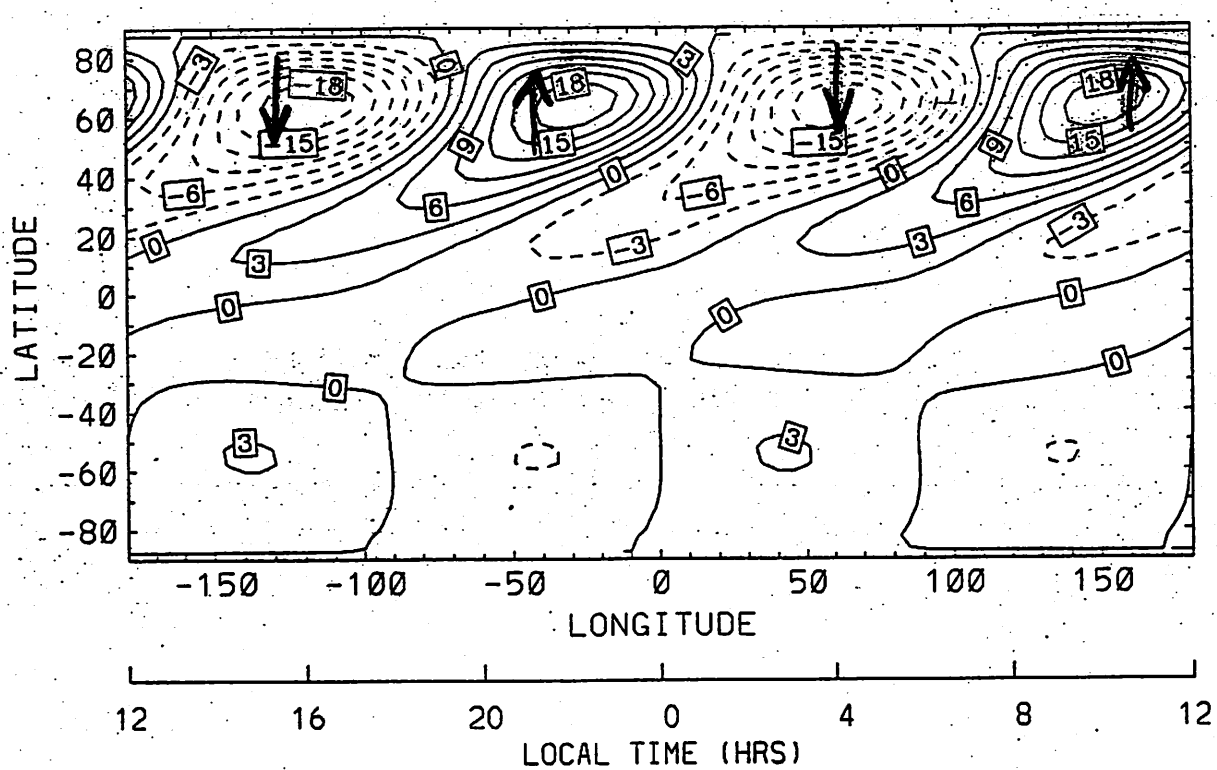
~97 km



MIN −27.93, MAX 30.70, INTERVAL 4

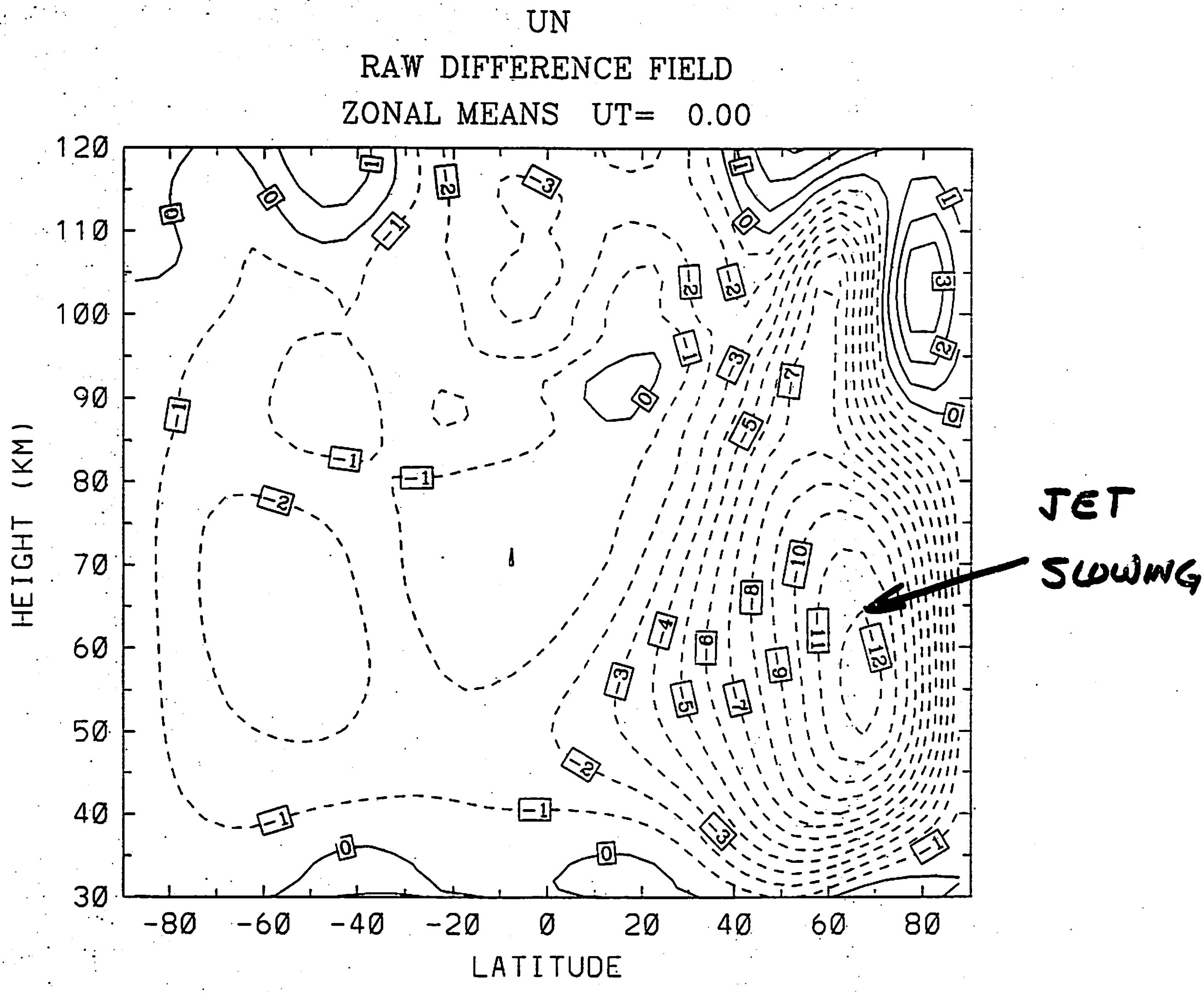
ZP=−15.0 UT= 0.00

~50 km



ZONAL MEAN ZONAL WIND DIFF

$$\Delta \overline{U} = \overline{U}_{PW} - \overline{U} \quad (m/s)$$



MIN −12.53, MAX 3.78, INTERVAL 1

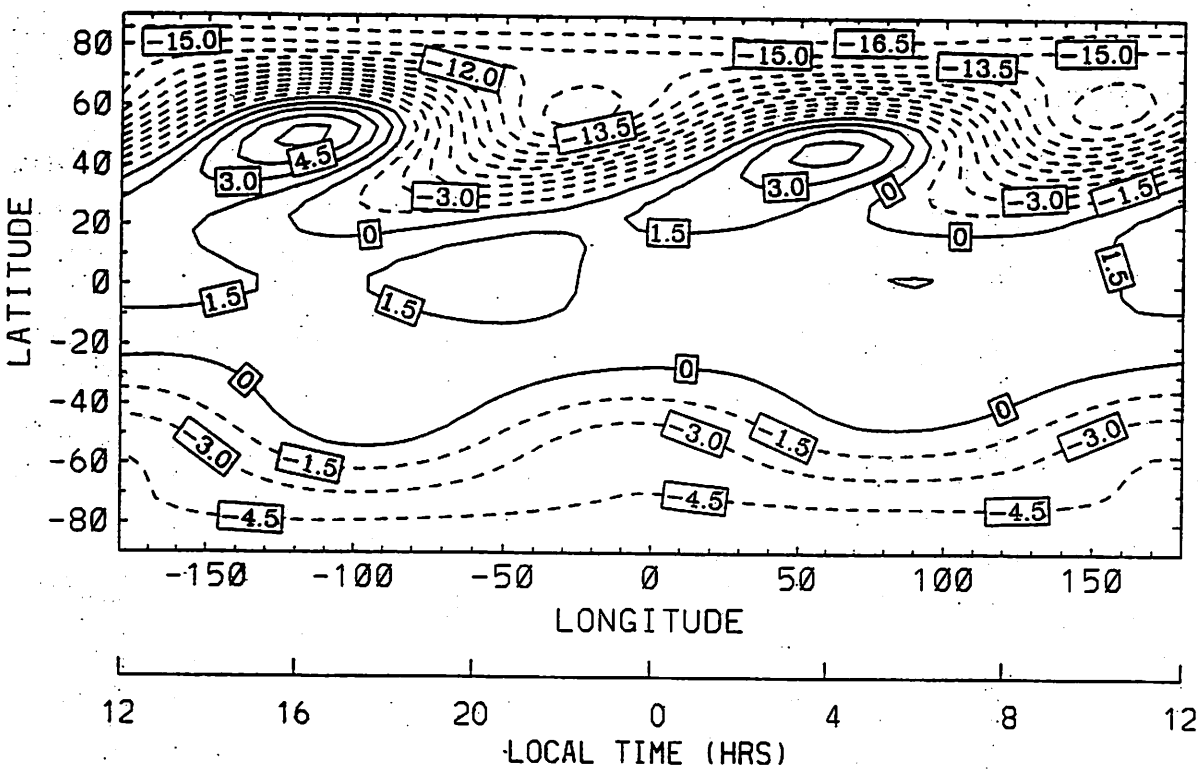
DIFFS FROM T17PW9 MINUS T17LB2

O3

PERCENT DIFFERENCE FIELD

ZP=-15.0 UT= 0.00

50KM



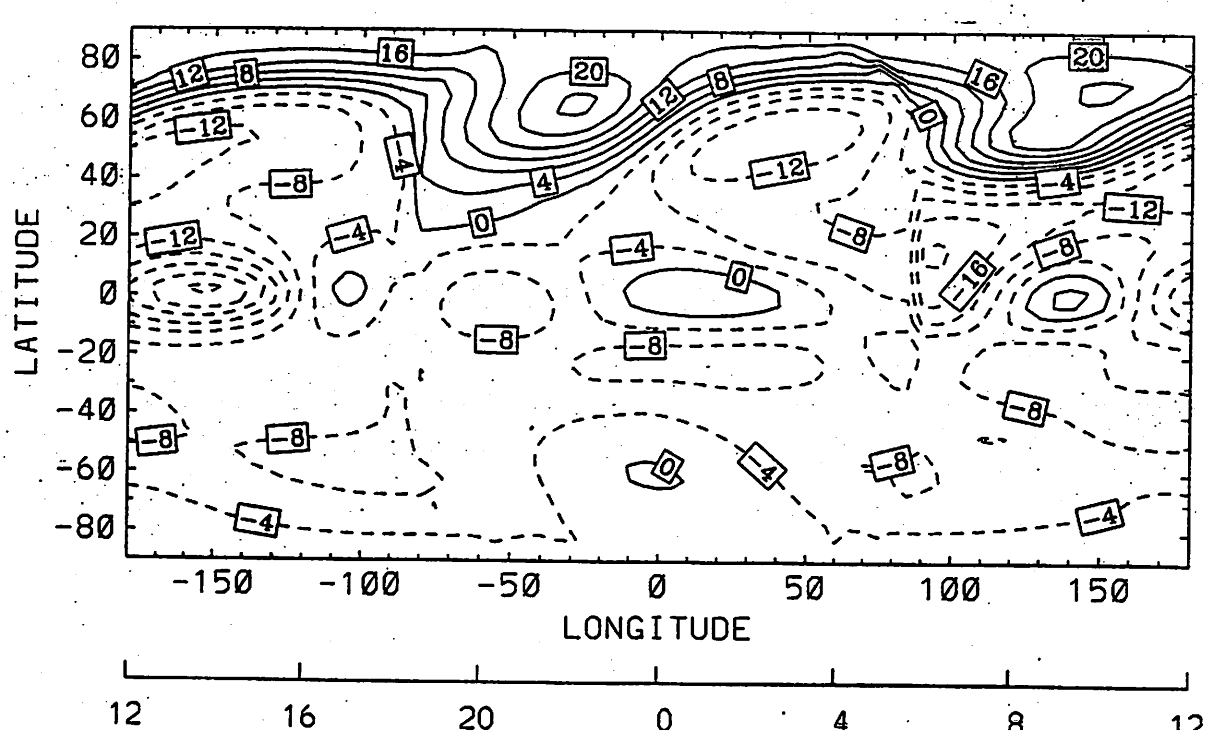
MIN -17.47, MAX 6.38, INTERVAL 1.5

OH

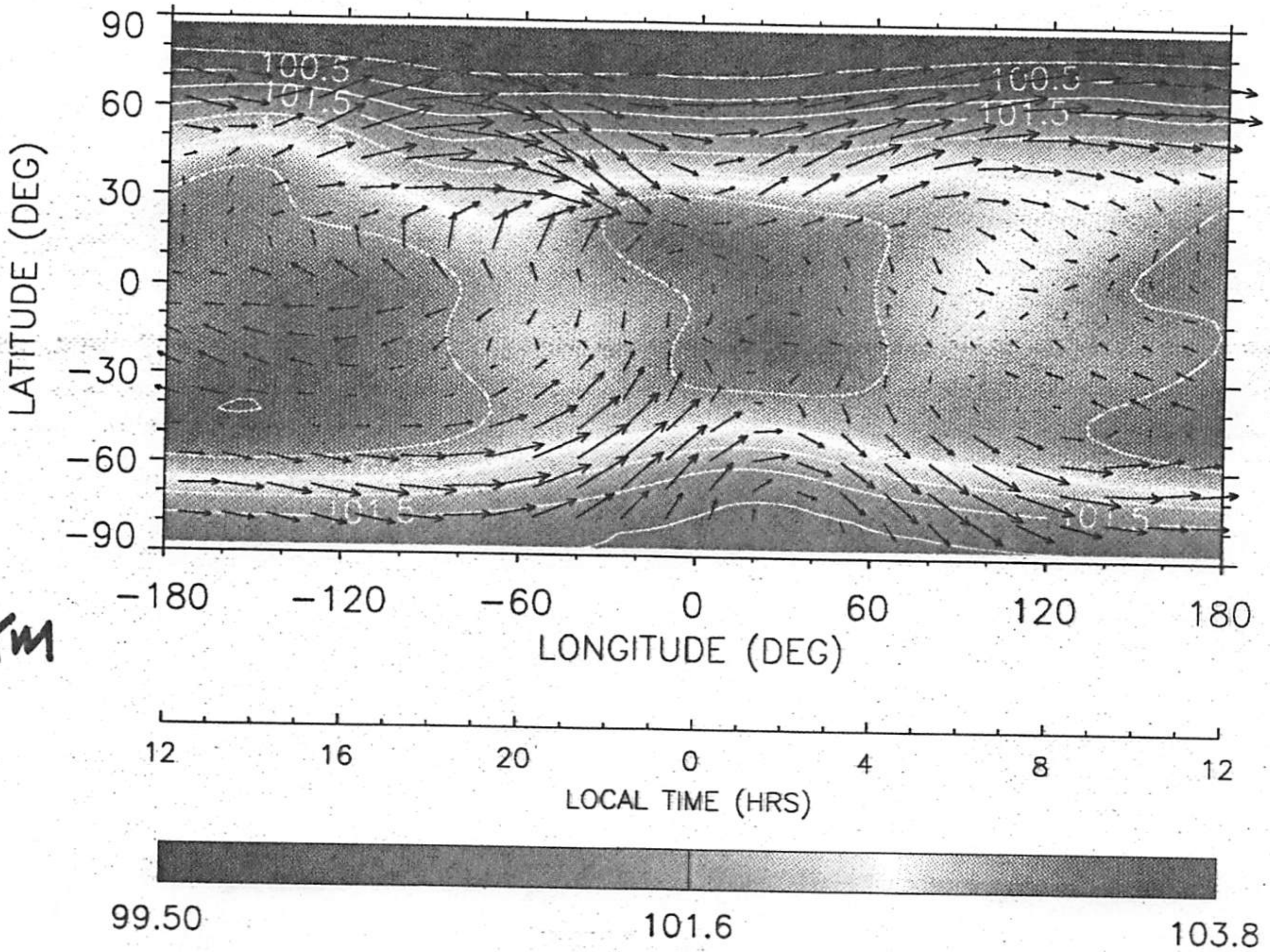
PERCENT DIFFERENCE FIELD

~85KM

ZP= -9.0 UT= 0.00

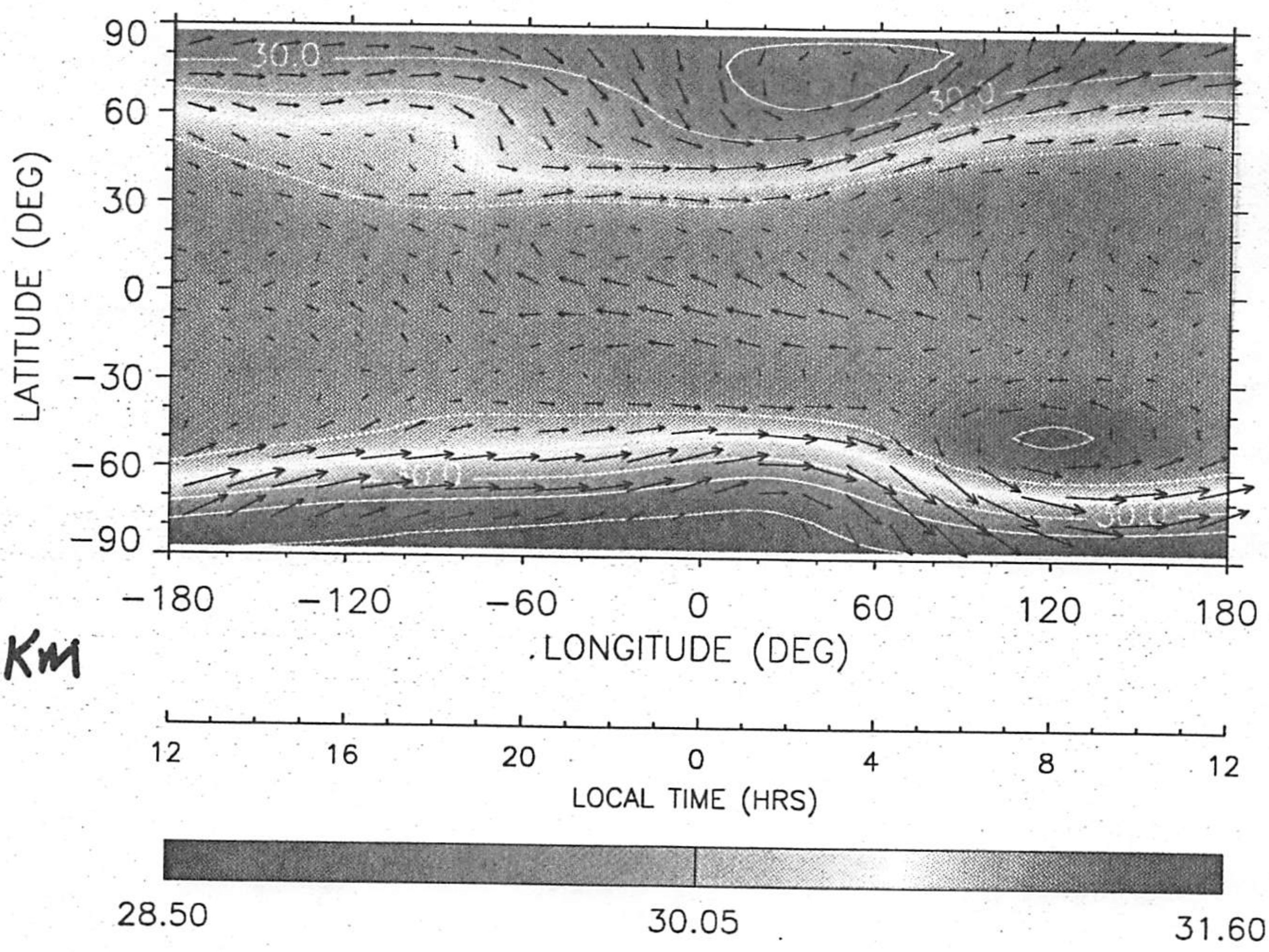


TIMESGCM Z (UN+VN) ZP = -7.0 UT = 0.0

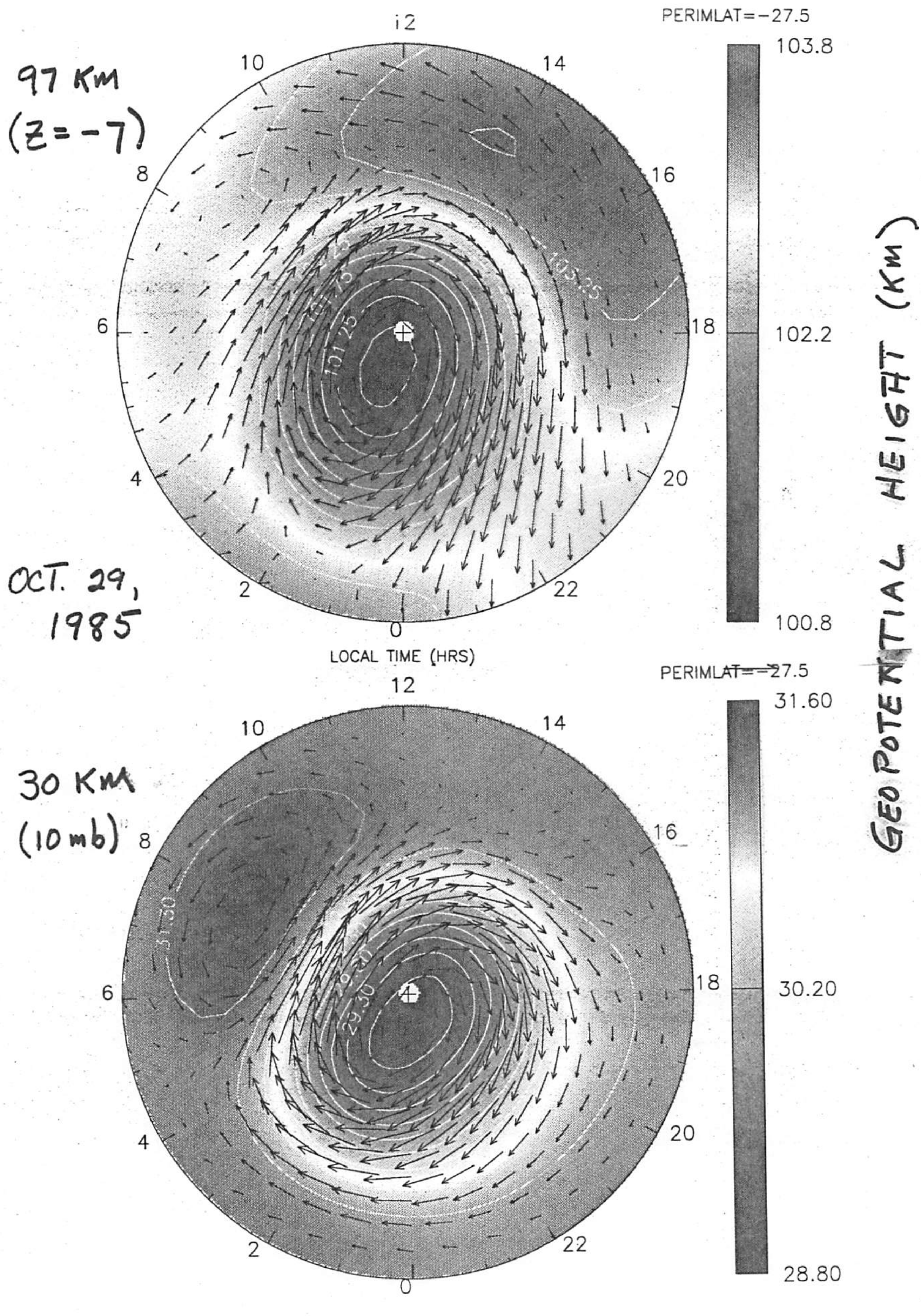


~97 Km

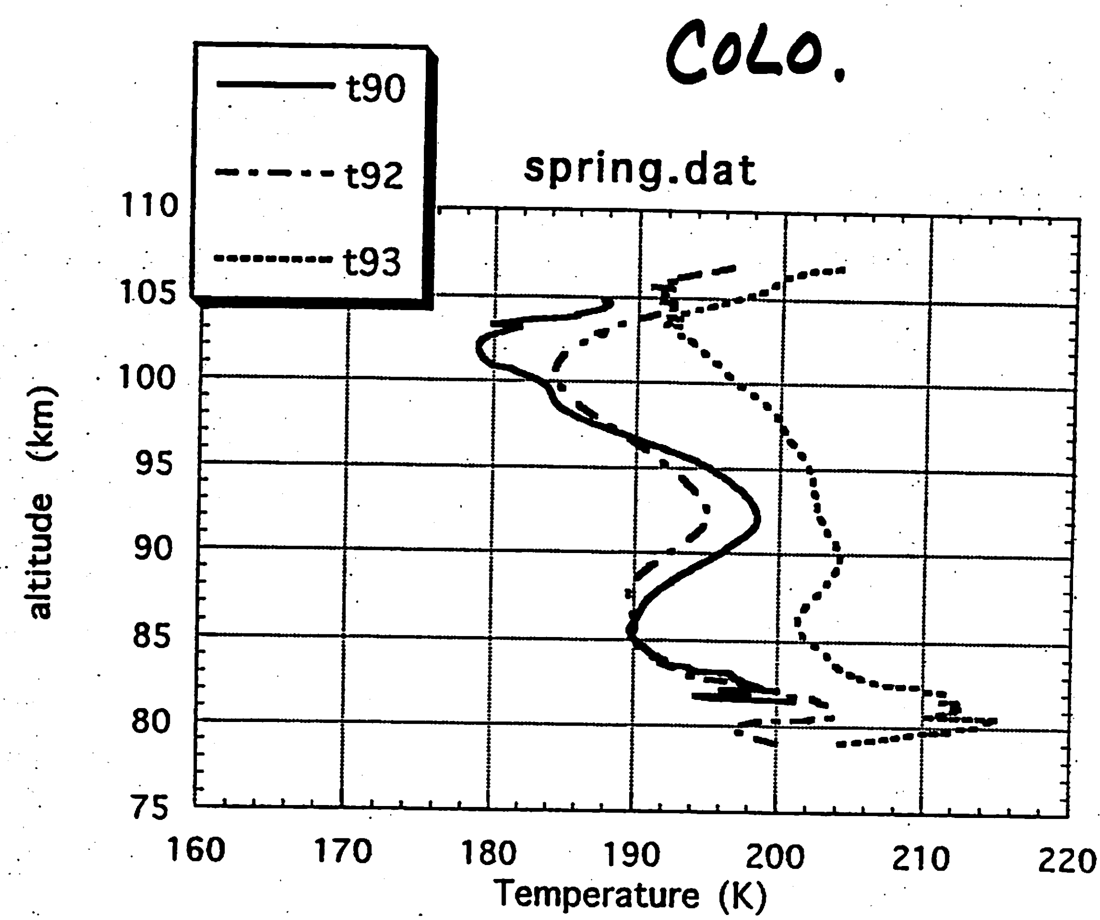
TIMESGCM Z (UN+VN) ZP = -17.0 UT = 0.0

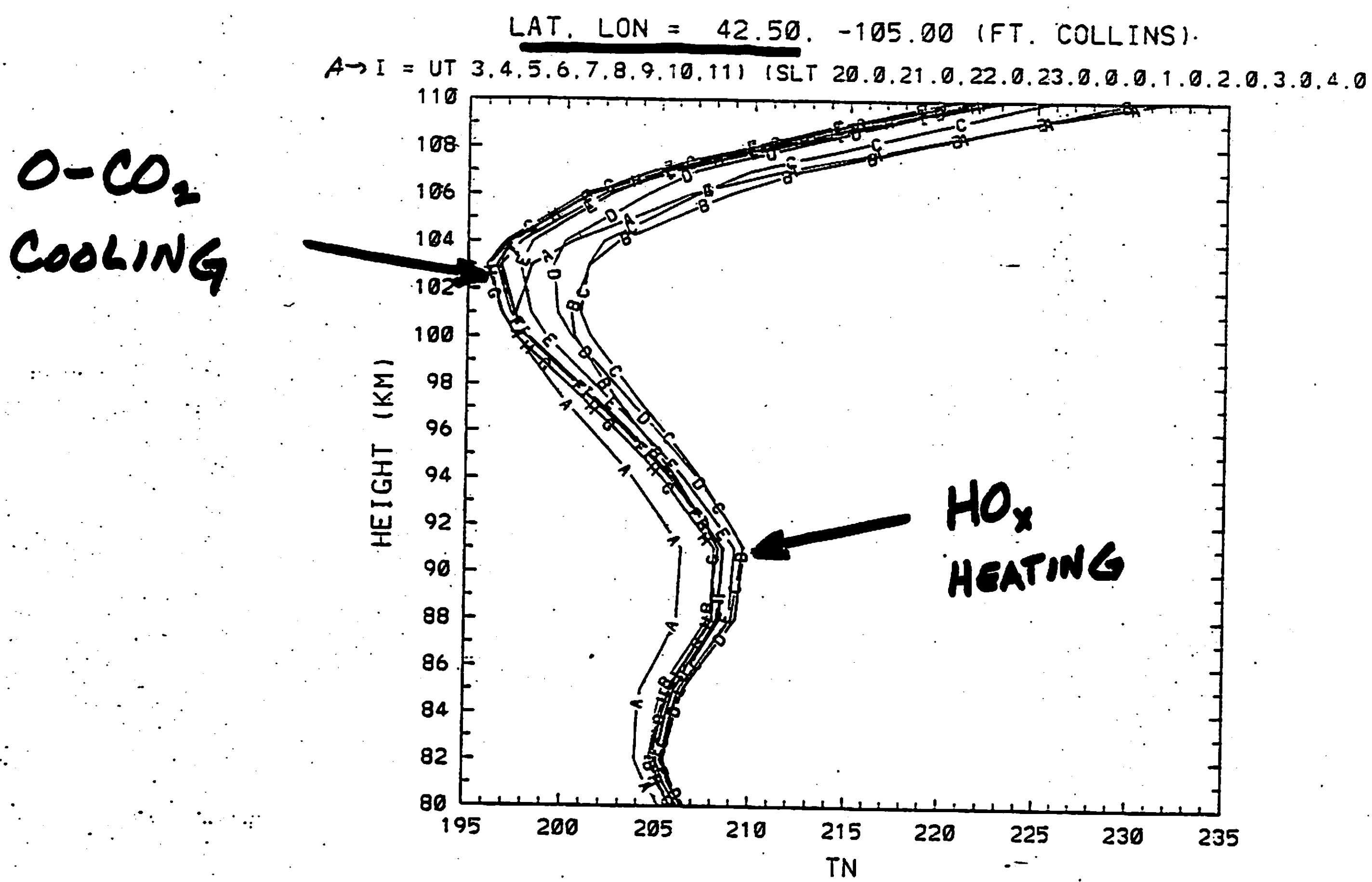


~30 Km

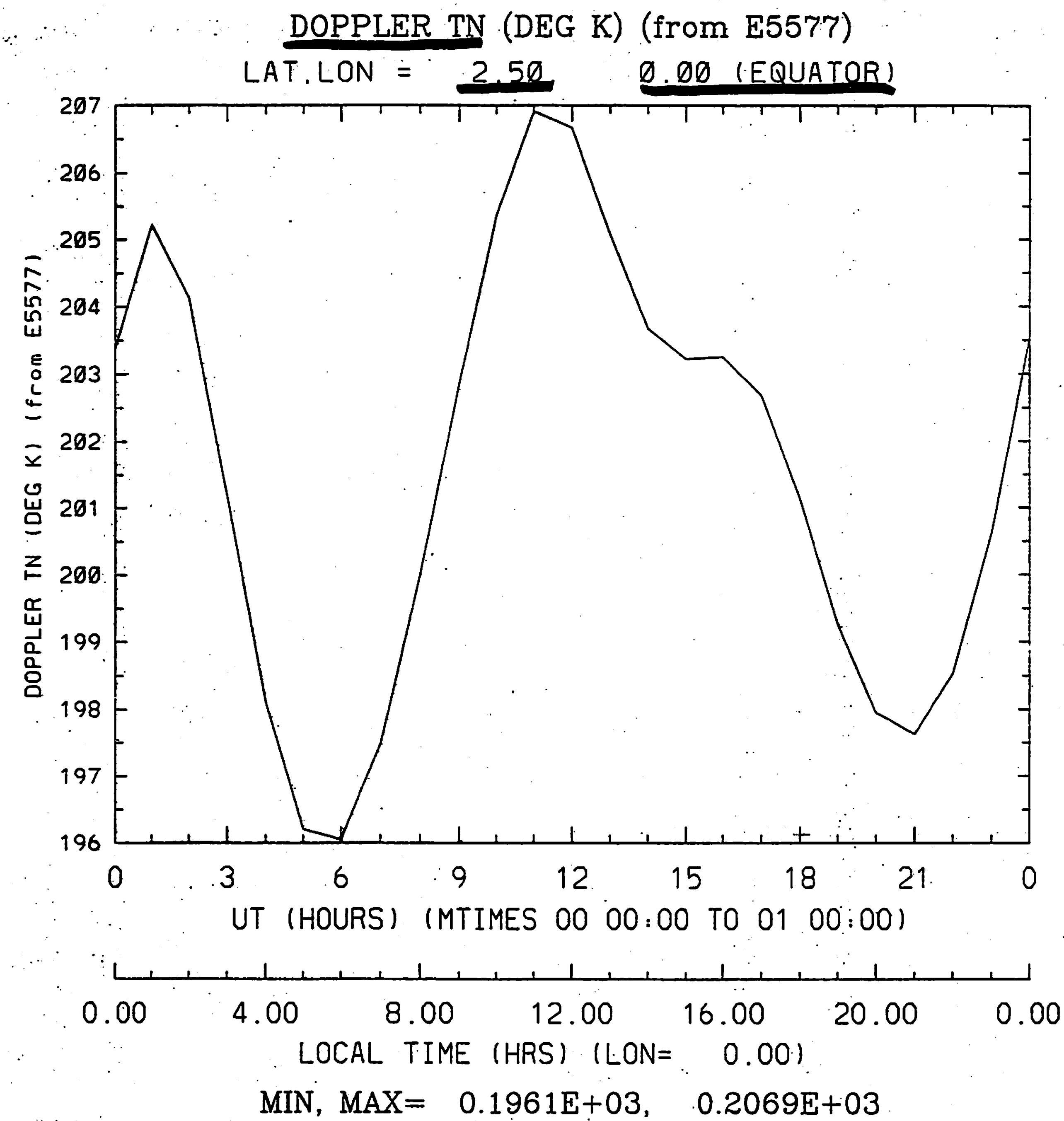


97 KM
(Z= -7)
OCT. 29,
1985
PERIMLAT=-27.5
103.8
102.2
100.8
LOCAL TIME (HRS)
30 KM
(10mb)
PERIMLAT=-27.5
31.60
30.20
28.80
GEOPOTENTIAL HEIGHT (KM)


COLO.
t90
t92
t93
spring.dat
altitude (km)
Temperature (K)


LAT, LON = 42.50, -105.00 (FT. COLLINS)
A→I = UT 3,4,5,6,7,8,9,10,11) (SLT 20.0,21.0,22.0,23.0,0.0,1.0,2.0,3.0,4.0)
O-CO_2 COOLING
HO_x HEATING
HEIGHT (KM)
TN

~100 Km λ 5577 Å



SUMMARY

- TIME-GCM (30-500KM), UP AND RUNNING ⟶ CEDAR STUDIES

  + CONTROLLED EXPERIMENTS

  + NMC-10MB, SOLAR, AURORAL FORCINGS

  + PROCESSORS FOR ANALYSIS OF CEDAR, UARS, ETC. DATA

  + COMMUNITY MODEL